Teaching About and Using Coordinate Systems

Teaching about coordinate systems is an excellent means of integrating geography and mathematics, incorporating fieldwork, and paving the way for understanding GPS and GIS in education. A coordinate system is a way to reference, or locate, everything on the Earth's surface in x and y space. The method used to portray a part of the spherical Earth on a flat surface, whether a paper map or a computer screen, is called a map projection. Each map projection used on a paper map or in a GIS is associated with a coordinate system. To simplify the use of maps and to avoid pinpointing locations on curved latitude-longitude reference lines, cartographers superimpose a rectangular grid on maps. Such grids use coordinate systems to determine the x and y position of any spot on the map. Coordinate systems are often identified by the name of the particular projection for which they are designed.

Because no single map projection is suitable for all purposes, many different coordinate systems have been developed. Some are worldwide or nearly so, while others cover individual countries (such as the United Kingdom's Ordnance Survey's coordinate system), and others cover states or parts of states in the U.S.

An effective way to introduce coordinate systems to students is to begin with the Cartesian coordinate system. Get out that graph paper! Talk about which quarters in the Cartesian coordinate system are positive for x and y, and which are negative for x and y.

Geographic Coordinate System (Latitude-Longitude)

The Geographic Coordinate System, which uses latitude and longitude to describe locations on the Earth's surface, is the map system most familiar to students and the one most often taught in schools. Latitude can be thought of as the lines that intersect the y-axis, and longitude as lines that intersect the x-axis. Think of the equator as the x axis; the y axis is the prime meridian, which is a line running from pole to pole through Greenwich, England. Just as the upper right quarter in the Cartesian coordinate system is positive for both x and y, latitude and longitude east of the prime meridian and north of the equator are both positive. Europe, Asia, and part of Africa – which have positive latitudes and longitudes – correspond to the upper right quarter of the Cartesian coordinate system. With the exception of some U.S. territories in the Pacific and the westernmost Aleutian islands, all of the United States is north of the equator and *west* of the prime meridian, so all latitudes in the U.S are positive (or north) while almost all longitudes are negative (or west).

Draw a cross section of the globe on the board and indicate that the angle between the equator and a line running "up" to the North Pole is 90 degrees, which is why the North Pole is 90 degrees north. An angle between the equator and Washington, D.C. is 38 degrees, so Washington, D.C. has a latitude of 38 degrees north. What would be the halfway point between the pole and the equator? Is your school closer to the equator or to the North Pole? What is the latitude and longitude of your school? What are the latitudes and longitudes of the northernmost, southernmost, easternmost, and westernmost points in the United States? Elevations and Distances in the United States is a fun reference for this exercise.

In a strict sense, latitude-longitude is not really a coordinate system because their grid does not have straight sides. However, it can be used as any other coordinate system to refer to the position of objects. One just needs to keep in mind that a degree of longitude is not constant over the Earth's surface, but decreases from 69 miles at the equator to zero at the poles. One effective way to illustrate this convergence is to compare a USGS 1:24,000-scale map from the northern part of the United States (Maine or Alaska, for example), and one from the southern part (Florida or Hawaii). They both span 7.5 minutes of longitude, but the map of Maine or Alaska will be narrower than the map of Florida or Hawaii.

There are three commonly used ways of displaying latitudes and longitudes, all based on the idea of precision. To illustrate precision, let's say Joe has arranged to meet Angela at 4pm in the cafeteria. If Angela shows up at 3:58pm and Joe arrives at 4:02pm, it's not a problem—the agreed upon time was understood to be approximate. Now say that Angela is appointed Chief of NASA Johnson Space Center. She wouldn't say, "We'll launch the rocket at about 4pm." If she says 4pm, she means **exactly** 4:00:00pm, because many things need to happen at .01 seconds before the launch, .05 seconds before the launch, and so on. A high degree of precision is required for some things, but for other things less precision is needed. Illustrate for your students what would happen if they rounded the coordinates of their school to the nearest latitude and longitude. Where is this point on the Earth's surface? It could be dozens of kilometers from the school.

All three common methods for displaying latitude and longitude can be used to teach geographic and mathematical concepts. The first method is degrees-minutes-seconds. For more precision, we divide each degree of longitude and latitude into 60 minutes and each minute into 60 seconds, much like time on a clock. A USGS 1:24,000-scale topographic map covers 7.5 minutes of latitude and 7.5 minutes of longitude. Give students a 1:24,000-scale topographic map and have them compute the distance in minutes between the corners of the map to verify that the map truly covers 7.5 x 7.5 minutes. The second method of displaying latitude-longitude is decimal minutes, or fractions of a minute. Latitude 40 degrees 30 minutes 7 seconds north in degrees-minutes-seconds is the same as latitude 40 degrees 30.117 in decimal minutes. The third method is decimal degrees. This same latitude is $(40 + 30/60 + 7/3600) = 40.502$ in decimal degrees.

40 degrees 30 minutes 7 seconds north
40 degrees 30.117 minutes north
40.502 degrees north
all represent the same latitude.

Universal Transverse Mercator (UTM)

A second coordinate system is the Universal Transverse Mercator grid, commonly referred to as UTM and based on the Transverse Mercator projection. Latitude-longitude is valuable because one can use the globe to introduce the concept and because it is the first coordinate system that students learn. However, in latitude-longitude, there may be 7 seconds between one end of a large building to the other, or (7/3600) = .0019 degrees. Seconds and fractions of degrees can be difficult distances to visualize and work with. In contrast, the UTM unit is the meter, a length that students already understand. UTM was created by the National Geospatial Intelligence Agency (NGA, formerly NIMA). UTM covers most of the planet except for polar regions. In this system, the world is divided into sixty north-south zones, each 6 degrees wide.

UTM zones are numbered consecutively beginning with Zone 1. Zone 1 covers 180 degrees west longitude to 174 degrees west longitude (6 degrees of longitude), and includes the westernmost point of Alaska. Maine falls within Zone 16 because it lies between 84 degrees west and 90 degrees west. In each zone, coordinates are measured as northings and eastings in meters. The northing values are measured from zero at the equator in a northerly direction (in the southern hemisphere, the equator is assigned a false northing value of 10,000,000 meters). The central meridian *in each zone* is assigned an easting value of 500,000 meters. In Zone 16, the central meridian is 87 degrees west. One meter east of that central meridian is 500,001 meters easting.

Using a GPS or a topographic map, ask students if the numbers increase or decrease as they walk north, east, south, and west. Since UTM coordinates of 490,000 meters easting and 4,300,000 meters northing exist (for example) in both California and Virginia, the correct zone must always be listed when giving UTM coordinates. UTM is especially effective with GPS because the student can clearly see the numbers changing by one meter each time a giant step is taken.

In which UTM zone is your school located?

State Plane Coordinate System

A third coordinate system is the State Plane Coordinate System. This system is actually a series of separate systems, each covering a state, or a part of a state, and is only used in the United States. It is popular with some state and local governments due to its high accuracy, achieved through the use of relatively small zones. State Plane began in 1933 with the North Carolina Coordinate System and in less than a year it had been copied in all of the other states. The system is designed to have a maximum linear error of 1 in 10,000 and is four times as accurate as the UTM system.

Like the UTM system, the State Plane system is based on zones. However, the 120 State Plane zones generally follow county boundaries (except in Alaska). Given the State Plane system's desired level of accuracy, larger states are divided into multiple zones, such as the “Colorado North Zone.” States with a long north-south axis (such as Idaho and Illinois) are mapped using a Transverse Mercator projection, while states with a long east-west axis (such as Washington and Pennsylvania) are mapped using a Lambert Conformal projection. In either case, the projection's central meridian is generally run down the approximate center of the zone.

A Cartesian coordinate system is created for each zone by establishing an origin some distance (usually 2,000,000 feet) to the west of the zone's central meridian and some distance to the south of the zone's southernmost point. This ensures that all coordinates within the zone will be positive. The X-axis running through this origin runs east-west, and the Y-axis runs north-south. Distances from the origin are generally measured in feet, but sometimes are in meters. X distances are typically called eastings (because they measure distances east of the origin) and Y distances are typically called northings (because they measure distances north of the origin).

Coordinates on Topographic Maps

Latitude-longitude, UTM coordinates, and State Plane coordinates are all indicated on modern USGS topographic maps. A standard 1:24,000 scale topographic map can be used to determine the coordinates for a point anywhere in the conterminous U.S. using all three systems. A USGS document on topographic map margins describes how to read the appropriate information in the map's collar.

Some USGS topographic maps also indicate townships, ranges, and sections using the Public Land Survey System (PLSS). This should not be confused with a coordinate system. The PLSS was created to divide parcels of public land and is not useful for the accurate location of individual points.

Have students use a topographic map, and/or a GPS unit to determine the coordinates of a point in all three of the coordinate systems described here. They will need to interpolate to get the correct coordinates from the map (it's a great math exercise!).

Datums

All coordinate systems are tied to a datum. The concept of datums can be difficult to grasp and difficult to teach, so there is a strong temptation to gloss over it. However, it is *critical* for GPS users to understand that different datum settings on their GPS receiver could result in different coordinate readings, and if the GPS receiver is set on a datum that is different from that used on a topographic map, the GPS coordinates and the map coordinates might disagree by quite a bit. Remember the earlier discussion about precision and the analogy with the launch of a NASA rocket? If Angela accidentally launched the rocket at 3:59 or 4:01 rather than 4:00:00 precisely, the consequences could be very serious. Plotting a point at the wrong location due to an incorrect datum setting can cause enormous problems.

A datum defines the starting point from which coordinates are measured. Latitude and longitude coordinates, for example, are determined by their distance from the equator and the prime meridian that runs through Greenwich, England. But where *exactly* is the equator? And where *exactly* is the Prime Meridian? And how does the irregular shape of the Earth figure into our measurements? All of these issues are defined by the datum.

Many different datums exist, but in the United States only three datums are commonly used. The North American Datum of 1927 (NAD27) uses a starting point at a base station in Meades Ranch, Kansas and the Clarke Ellipsoid to calculate the shape of the Earth. Thanks to the advent of satellites, a better model later became available and resulted in the development of the North American Datum of 1983 (NAD83). Depending on one's location, coordinates obtained using NAD83 could be hundreds of meters away from coordinates obtained using NAD27. A third datum, the World Geodetic System of 1984 (WGS84) is identical to NAD83 for most practical purposes within the United States. The differences are only important when an extremely high degree of precision is needed. WGS84 is the default datum setting for almost all GPS devices. But most USGS topographic maps published up to 2009 use NAD27. This conflict in datums can cause big problems for the uninformed GPS user.

If GPS units are available, have your students obtain coordinates for several points using NAD27, NAD83, and WGS84. This will require changing the datum setting for each reading. Plot the points on a USGS 1:24,000 scale topographic map of the area. How do the coordinates for each datum setting differ? Is that difference consistent from point to point? Discuss the possible real-life consequences of plotting coordinates in the wrong place because of an incorrect datum setting.

Datums on Topographic Maps

Most paper USGS topographic maps were created using NAD27, but a small number of newer topographic maps use NAD83. The map's datum is listed in the credit legend in the lower left part of the map collar. If you are plotting points obtained with a GPS unit on a topographic map, be sure your GPS unit is set for the correct datum. Beginning in 1984, all USGS topographic maps have a dashed cross in each corner that indicates the degree of offset between NAD27 and NAD83. The new generation of digital USGS topographic maps ("US Topo") that will be available in 2010 all use NAD83.

Useful references:

Map Projections Poster
http://egsc.usgs.gov/isb//pubs/MapProjections/projections.html

Map Projections Article
http://nationalatlas.gov/articles/mapping/a_projections.html

Transverse Mercator Projection
http://egsc.usgs.gov/isb//pubs/MapProjections/projections.html#transverse

Lambert Conformal Projection
http://egsc.usgs.gov/isb//pubs/MapProjections/projections.html#lambert2

Latitude and Longitude
http://nationalatlas.gov/articles/mapping/a_latlong.html

Elevations and Distances in the United States
http://egsc.usgs.gov/isb//pubs/booklets/elvadist/elvadist.html

UTM Coordinates
http://pubs.er.usgs.gov/publication/fs07701

State Plane Coordinate System
http://www.usgs.gov/faq/?q=categories/9794/3025

Map Margins
http://education.usgs.gov/ lessons/mapmargin.pdf

Public Land Survey System
http://nationalatlas.gov/articles/boundaries/a_plss.html

The National Grid
http://www.fgdc.gov/usng/USNGInfoSheetsCv5_4pages.pdf

How to obtain USGS Topographic Maps

- Download free digital topographic maps in a GeoPDF format by going to the USGS Store (http://store.usgs.gov) and clicking on "Map Locator & Downloader". You have the option of choosing between two types of topographic maps:
    1. US Topo maps – computer generated and updated every three years. These maps have different layers that can be turned on and off, including an orthophoto (air photo) layer. Learn more at: http://nationalmap.gov/ustopo/
    2. Historical topographic maps – made by hand, but not updated since 2003 (or earlier). Although these maps are outdated, they were optimized for readability. Students who are just learning about maps might find them easier to use than the US Topo maps. Learn more at: http://nationalmap.gov/historical/index.html
- Order paper copies of both US Topo maps and historical topographic maps through the same Map Locator Web site (http://store.usgs.gov).
- Questions? Need help? Call 1-888-ASK-USGS (1-888-275-8747) or go to http://www.usgs.gov/ask