NASA Quest Challenge

Part I: Charting a Course at Sea

Acknowledgments

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Planners Collaborative Education Team

- Linda Conrad, Web Event Coordinator, NASA Ames Research Center
- Brian Day, LCROSS Education and Public Outreach Lead, NASA Ames Research Center
- Rebecca Green, Educator Guide Designer and Developer
- Barbara Patterson, Education Team Manager
- Will Shaw, Educator Guide Contributor and Editor

Partners

- ‘Imiloa Astronomy Center of Hawai’i, Hilo, Hawai’i

State of Hawaii Educators

- Jennifer Atkins, Substitute Teacher, Kea’au, Hawai’i
- Shannon De Luz, High School Science Teacher, Honoka’a, Hawai’i
- Gerrainne Horita, Elementary Teacher, Waipahu, Oahu
- Brenda Kikuyama, Elementary Technology Coordinator, Waipahu, Oahu
- Gail Loeffler, Science Coordinator, ‘Imiloa Astronomy Center of Hawai’i, Hilo, Hawai’i
- Marcia May, Elementary Teacher, Na’alehu, Hawai’i
- Stan Mesina, Elementary Technology Coordinator and Gifted & Talented Teacher, Waipahu, Oahu
- Joan Oshiro, Elementary Teacher, Waipahu, Oahu
- Bob Roman, STARBASE Hawaii Program Director, Kea’au, Hawai’i
- Theresa Seely, K-12 Special Education Teacher, Kohala, Hawai’i

Primary Sources of Content

- Kalepa Babayan, Resident Navigator, ‘Imiloa Astronomy Center of Hawai’i, Hilo, Hawai’i
- Polynesian Voyaging Society, “Wayfinding: Non-Instrument Navigation”
- PBS, “Wayfinders: A Pacific Odyssey”
- Wikipedia

Other Contributors

- Pierre Bierre, Principal Investigator, Algorithmic Geometry Project

Table of Contents

Overview

Purpose

Welcome to Part I of the NASA Quest Exploration Through Navigation Challenge! The purpose of this Challenge is to connect students in grades 5–8 to NASA's **L**unar **Cr**ater **O**bservation and **S**ensing **S**atellite (LCROSS) mission while teaching them about different methods of Earth-based and space-based navigation.

Learning Objectives

- Humans explore for reasons of necessity and curiosity, and exploration often leads to new innovations. Navigation skills are tools of exploration.
- There are different methods of navigation, and these methods vary whether you are at sea or in space.
- One method of navigation that is common to both voyages at sea and in space is celestial navigation (the use of planets, moons, and stars).
- Using multiple methods of navigation is better than relying on only one method.

Summary

The major concept or "big idea" behind this Challenge is **exploration**, with the content centering on **navigation** skills. The essential question posed to students is "**How will you stay on course?**" In Part I of this Challenge, students will be tasked to chart a course from the Big Island of Hawai'i to Rapa Nui (Easter Island) using ocean navigation skills that were used in early Polynesian exploration. Outside of the classroom, students will track the star Enif and determine if there is a relationship between the latitude of the observation site and the star's altitude at its upper culmination. Then, in Part II of the Challenge*, students will be tasked to chart a course from Kennedy Space Center at Cape Canaveral, Florida, to one of the lunar poles using navigation skills appropriate for outer space. For both tasks, students will submit a navigation plan (as a class) to NASA Quest for experts to review. At the end of the Challenge, students will compare and contrast methods of navigating on Earth (at sea) and in space.

Classroom Deliverables

Part I: Hawai'i to Rapa Nui	Part II: Earth to Moon*
• Map of ocean route	• Map of space route
• Navigation plan (format provided)	• Navigation plan (format provided)
• Visual representation of method(s)	• Visual representation of method(s)
• Star tracking data: latitude & altitude	• Compare/contrast Earth & Space nav

** See note on page 5 regarding Part II of the Challenge.*

Structure

The structure of this Challenge is based on the Moenaha adaptation of the 4MAT method of learning used by the ‘Imiloa Astronomy Center of Hawai’i. In this model, four driving questions are used to guide students through the learning process: Why? What? How? and If?

Ho’olohe: The Challenge begins by sparking the students’ interest and bringing meaning to the task at hand with the question, “Why do humans explore?” Here the Challenge is made relevant to students’ lives through images, stories, and discussion.

Ho’opili: Next, information is gathered and key concepts are taught relating to navigation methods used on Earth (Part I) and in space (Part II*). In Part I, special focus will be given to the ancient art of Polynesian wayfinding at sea.

Ho’ohana: After students explore select methods of navigation, they apply the skills they have learned by developing a strategy for navigating a Polynesian canoe from the Big Island of Hawai’i to Rapa Nui.

During this portion of the Challenge, classes submit their navigation plans to the NASA Quest Challenge team in the form of an image, explanatory text, and map of their route. Subject matter experts offer the classes feedback and guidance, and students, in turn, refine and submit their final plans as to how they will “stay on course” and navigate to their destination. Also, as an out-of-the-classroom hands-on activity, students track the star “Enif” and, as a class, submit their observation site’s latitude and the star’s altitude during its upper culmination to the NASA Quest Challenge team. Observation data from all classes will be compiled and charted, and students will analyze the data and draw conclusions.

Ho’opuka: At the end of the Challenge, students expand the possibilities of their new-found knowledge by exploring the questions, “If I can navigate, where will I go?” and “What new methods of navigation can I explore?”

***Note**: The “Exploration Through Navigation” Challenge is divided into two parts.

Part I of the Challenge, which focuses on ocean navigation methods used on Earth, is being held in the Fall 2008. This educator guide supports Part I of the Challenge.

Part II of the Challenge, which focuses on space navigation methods, will be held in the Winter/Spring 2009. A separate guide will be distributed for Part II of the Challenge in early 2009.

CHARTING A COURSE AT SEA

Concept or Big Idea: Exploration

Content and Skills: Navigation

Major Understandings:

- Navigation skills are tools of exploration.
- There are different methods of navigation.
- One common method on Earth and in space is celestial navigation.
- It is advantageous to utilize multiple navigation methods.

Essential Question:

How will YOU stay on course?

Driving Questions:

Why? (motivate)
Exploration is a natural human endeavor that leads to human expansion and invention.

What? (teach)
Navigation skills are tools used in exploration on Earth and in space

How? (apply)
Practice and refine navigation skills and then extend and verify new knowledge

If?... (empower)
Consider places to explore with newly acquired wayfinding skills or create new ways to navigate

National Standards

Language Arts	
NL–ENG.K–12.1, Reading for Perspective	Build an understanding of cultures; Acquire new information
NL–ENG.K–12.4, Communication Skills	Use spoken, written, and visual language to communicate effectively with a variety of audiences
NL–ENG.K–12.8, Developing Research Skills	Use a variety of technological and information resources to gather and synthesize information and to communicate knowledge
NL–ENG.K–12.9, Multicultural Understanding	Develop an understanding of and respect for diversity in language
Geography	
NSS–G.K–12.1, The World in Spatial Terms	Use maps and other geographic representations, tools, technologies to acquire, process, and report information
NSS–G.K–12.2, Places and Regions	Understand the physical and human characteristics of places; Understand how culture and experience influence people's perceptions of places
NSS–G.K–12.4, Human Systems	Understand the characteristics, distribution, and migration of human populations; Understand the processes, patterns, and functions of human settlement
World History	
NSS–WH.5–12.2, Early Civilizations 4000-1000 BCE	How agrarian societies spread and new states emerged in millennia BCE
Science	
NS.K–4.2, 5–8.2, Physical Science	Position and motion of objects; Motions and forces; Transfer of energy
NS.K–4.4, 5–8.4, Earth and Space Science	Objects and changes in earth and sky; Earth in the solar system
NS.K–4.5, 5–8.5, 9–12.5, Science and Technology	Abilities and understanding of technological design; natural vs. human-made objects
NS.K–4.7, 5–8.7, 9–12.7, History of Nature and Science	Science as a human endeavor
Technology	
NT.K–12.4, Technology Communication Tools	Use telecommunications to collaborate and interact with peers and experts

Vocabulary

bearing - the horizontal direction of one point with respect to the compass; determination of position

celestial - positioned in or pertaining to the sky or outer space

constellation - a group of stars forming a recognizable pattern

culmination - the highest point a star reaches in the sky in relation to the horizon

equator - the great circle of the earth that is perpendicular to the earth's axis and is equidistant from the north and south poles. It marks 0º latitude and divides the earth into the northern and southern hemispheres.

diurnal - recurring every day; having a daily cycle; of or resulting from the daily rotation of the earth

doldrums - a belt of low pressure around the equator where the prevailing winds are calm and the ocean current reverses direction

innovation - a new method, idea, or product

knot - a unit of speed equal to one nautical mile per hour

latitude - the angular distance of a point north or south of the equator measured in degrees

LCROSS - **L**unar **C**rater **O**bservation and **S**ensing **S**atellite. An unmanned, robotic NASA mission scheduled for Spring 2009 that will search for frozen water at the Moon's polar region

longitude - the angular distance of a point east or west of the prime meridian measured in degrees

nautical mile - unit of distance equaling 1,852 meters (~2,025 yards or ~1.15 land miles) used for ocean and air navigation based on the length of a minute of arc of a great circle of the earth

navigation - the art or science of directing the course of a ship; method of determininig position, course, and distance traveled

Polynesia - the islands of the central and south Pacific ocean

prevailing wind - a wind that blows predominantly from a single general direction. The trade winds are prevailing winds that blow from east to west above and below the equator.

sidereal - of or with respect to the distant stars

typhoon - a tropical cyclone or hurricane of the Pacific ocean

voyage - a long journey involving travel by sea or in space

wayfinding - ways in which people and animals orient themselves in physical space and navigate from place to place

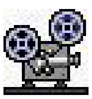
waypoint - a point between major points on a route

Ho'olohe (Why)

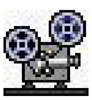
Driving Question:

In January 2004, the Vision for Space Exploration was announced as the United States space policy. This vision includes lunar robotic spacecraft missions slated for the year 2009. The **L**unar **Cr**ater **O**bservation and **S**ensing **S**atellite (LCROSS) is one of these Lunar Precursor Robotic Program missions that will hopefully lead the way to future human exploration of the Moon and beyond.

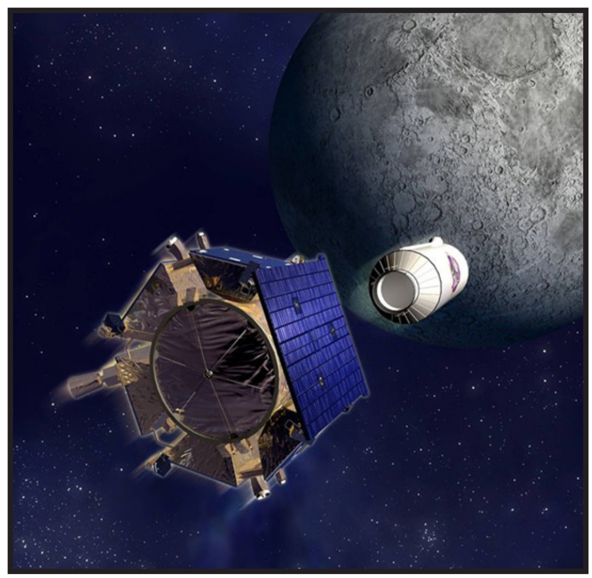
To excite students about this Quest Challenge, show the following two videos:



NASA exploration video: http://www.nasa.gov/externalflash/Vision/index.html (50 second introductory video plus additional features to explore)



NASA LCROSS video: http://lcross.arc.nasa.gov (4 minutes, 20 seconds)



LCROSS representation

As stated in the LCROSS video, the primary objective of the LCROSS mission is to search for the presence of water, in the form of ice, in a permanently shadowed crater near one of the Moon's poles. LCROSS will launch from Earth on an Atlas V rocket and then position itself on a course toward one of the lunar poles. Upon approach, the Atlas V's Centaur upper-stage rocket will separate from the LCROSS shepherding spacecraft and continue on its course to the lunar surface. The Centaur will impact the Moon, creating a debris plume that will rise above the lunar surface. The LCROSS shepherding spacecraft, following four minutes behind, will fly through the debris and collect data with a suite of instruments including spectrometers, cameras, and a radiometer. After relaying the data back to Earth, the shepherding spacecraft will impact the lunar surface, creating a second debris plume for scientists to analyze.

Transporting water and other goods from Earth to the lunar surface is expensive; therefore, finding natural resources, such as frozen water, on the Moon is important for future human exploration. If water exists, then it can be used in the process of establishing a lunar outpost, which would be a stepping stone to future exploration of the Moon as well as other bodies in our solar system.

Discussion

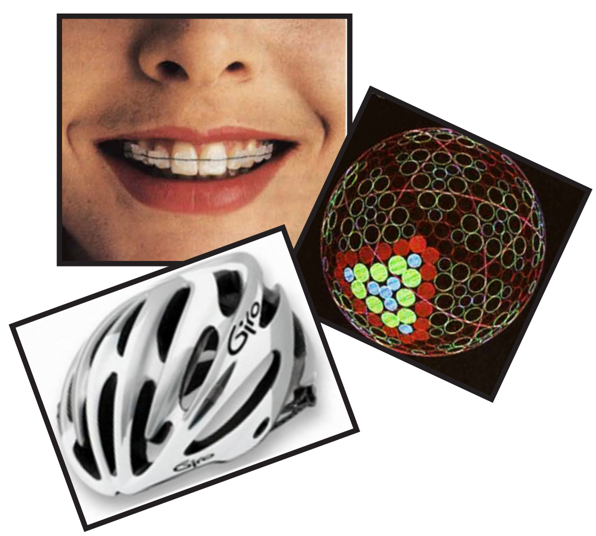
Hold a class discussion around the driving question, “Why do humans explore?”   Responses may include:

- **Necessity** – Since the earliest ages, humans have explored new territories for reasons such as growing populations, the search for food and natural resources, and the building and conquering of societies, etc. One example is the migration of the Polynesian cultures thousands of years ago. In some tribes, the eldest son received the family inheritance, so younger siblings had to provide for themselves and their families. Often these siblings would sail north to find land and resources that would support them. Since traveling north required sailing against the ocean current, it was harder to reach and therefore less likely to be overpopulated. (Read about Polynesian migration: http://pvs.kcc.hawaii.edu/L2migrations.html or http://www.pbs.org/wayfinders/polynesian.html)

Canoe off the coast of Hilo, Hawaii

- **Curiosity** – Humans are natural explorers. People inherently like to know about the world around them. By 1500 BCE, Polynesians were exploring the Pacific Ocean, and in the 15th and 16th centuries, many European explorers began traveling all over the world. By the 1950s and 1960s, human exploration expanded past our home planet and into outer space all the way to the Moon. This curiosity continues today through the desire for a future establishment of a lunar outpost, which would serve as a stepping stone for exploration of other regions in our solar system. (Read about lunar outposts: http://www.nasa.gov/mission_pages/exploration/mmb/lunar_architecture.html)

- **Innovation** – Exploration often leads to technological invention. Space exploration alone has resulted in many innovations. Shock-absorbing helmets, smoke detectors, and flat panel televisions are examples of “spinoff” technologies resulting from space exploration. (Read about NASA spinoff technologies: http://www.thespaceplace.com/nasa/spinoffs.html or http://www.sti.nasa.gov/tto/)



NASA Spinoff Technologies: invisible braces, symmetrical golf ball, and aerodynamic bike helmet

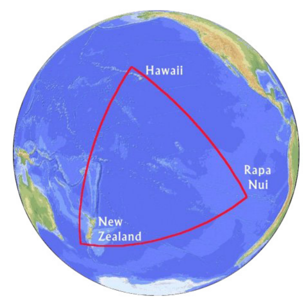
Ho'opili (What)

Driving Question:

Ancient Polynesian Wayfinding

Polynesia is a group of over 1,000 islands in the Pacific Ocean. These islands exist within the "Polynesian triangle," which stretches from Hawaii in the north to Rapa Nui (Easter Island) in the southeast to New Zealand in the southwest. Polynesia is comprised of many cultures, including the groups of Tonga, Niue, Samoa, and Fiji in the west and the groups of Tahiti, the Tuamotus, the Marquesas, Hawaii, Rapa Nui, and the Cook Islands in the east.

Wayfinding is the art of orienting oneself in physical space and navigating from place to place without the use of modern instruments. Throughout their existance, Polynesians have been expert canoe builders and master wayfinders capable of voyaging thousands of miles across the Pacific Ocean. They did not use any instrumentation to navigate. Instead, they traveled the vast ocean using a type of celestial navigation called "wayfaring," which means that they used information about the stars, Sun, Moon, planets, ocean, and tradewinds to know which way to go. They built boats with a system of rungs that would line up with key stars on the horizon for the navigator to determine direction. It took many years to train a navigator to understand how to observe and interpret these natural signs.



Polynesian Triangle

Navigating is a continuous process. Bearings are taken 24 hours a day to monitor and maintain a proper course. During the day, the navigator uses the Sun and waves (and Moon, if visible) to hold direction, while at night he or she follows the celestial objects of the night sky.


Comet Hale Bop

"Celestial navigation is one of the oldest human pursuits. So old that more ways to navigate have been forgotten than are now remembered. There have been many different methods for using the sky to navigate. No single method for navigating is perfect; each idea or device has merit."

Navigate Our World. *Celestial Navigation*
http://www.navigateourworld.com/Celestial_Navigation.html

Research

Rainbow on Hawai'i Island

As a class or in teams, have students explore one or more of the following Polynesian wayfinding techniques. Brief summaries of these topics are on pages 13–20 of this guide, and a list of web resources is provided on page 21.

- Sun
- Moon
- Planets
- Stars (North and South pointers, meridian pairs, constellations)
- Winds
- Clouds
- Ocean Swells and Currents
- Seamarks (birds, fish, plants)
- Landmarks

"Lacking writing, local navigators have had to commit to memory their knowledge of the stars, sailing directions, seamarks, and how to read the waves and clouds to determine currents and predict weather."

University of Pennsylvania Museum of Archaeology and Anthropology. *Traditional Navigation in the Western Pacific: A Search for Pattern.* Introduction. http://www.museum.upenn.edu/Navigation/intro.html

*** * * * * Mathematics at Sea – Check It Out! * * * * ***

The Pacific Ocean is immense, and it can be very difficult to sight a small, isolated island. Rapa Nui is one such island being that it is a small triangular piece of land measuring 13 x 11 x 10 miles with a height of only 1,674 feet (Cerro Terevaka). To find this island, wayfinders have to sail within 46 nautical miles of the island, in clear weather, during daylight hours.

According to the Polynesian Voyaging Society, the formula for seeing objects at sea is:

Distance in Nautical Miles = Square Root of the Object's Height (in feet) + Square Root of the Observer's Height (in feet)

Generally speaking, the height of an observer on a Polynesian canoe, when the observer climbs the mast, is approximately 25 feet high. Using this 25-foot guideline, have students calculate what distance in nautical miles a crew would have to be in order to see the Big Island of Hawai'i, whose highest point (Mauna Kea) measures 13,796 feet? (answer: *~122 nautical miles*)

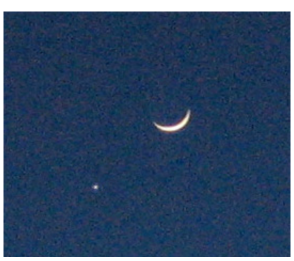
Note: *Students will not use the unit "feet" in their calculation. They will only use the square root values, and their answer will be in "nautical miles." In the case of Rapa Nui, the square root of 1,674 is ~ 40.91 and the square root of 25 is 5. If you add 40.91 and 5, then the answer is approximately 46 nautical miles.*

1. Sun and Moon

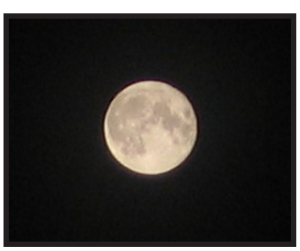
One method of wayfinding includes the observation of the rising and setting of the Sun and Moon.

Sunset off coast of Hawai'i

The Sun is the main guide for the navigator without instruments. Twice a day, at sunrise and at sunset, the Sun gives a directional point to the traveler as it rises in the east and sets in the west. However, as the Earth moves along its orbit, the precise rising and setting positions of the Sun change as its latitude changes throughout the year. At dawn, sailors can note how much the Sun has shifted by comparing its position with the fading stars. During the vernal (March 21) and autumnal (September 22) equinoxes, the Sun rises in the house of Hikina (due East) and sets in the house of Komohana (due west). Throughout the remainder of the year, the Sun slowly progresses northward or southward until it rises and sets in the house of 'Aina during the summer solstice (June 21) and winter solstice (December 22).



Moon and Venus



Full Moon

The Moon's rising and setting positions also change but even more quickly than those of the Sun. Each night the appearance and disappearance of the Moon occurs an average of about 50 minutes later than the night before. Because of this, the Moon will be in a different position in the sky each night, and its visibility will not occur at the same time every day. However, experienced navigators can use the rising and setting points of stars to determine where the Moon will appear on the horizon. The waxing Moon first becomes visible in the western sky around sunset; it is illuminated as a crescent by the Sun, which is in its western position. Then, when the full Moon begins to wane and its orbit has reached the opposite side of the Earth, it becomes visible after midnight as it is illuminated by the eastern sunlight. And of course, depending on the phase of the Moon and prevailing cloud cover, a bright moonlight offers a measure of safety and convenience in an otherwise dark night sky.

Sidereal Compass

To help orient the canoe to the rising and setting points of the stars, the wayfinder uses a star compass with 32 equidistant directional points around the horizon. Each point is 11.25º from the next point and serves as the midpoint of a "house" (or bearing) of the same name. The 32 houses, each measuring 11.25º, make up the 360º star compass. The Hawaiian star compass, also known as a sidereal compass, is an incredibly accurate way to navigate. By developing this navigation system, the ancient Polynesians were way ahead of their time.

Visit the two sites below to learn more about this important navigational tool.

1. **Polynesian Voyaging Society: Hawaiian Star Compass developed by Navigator Nainoa Thompson.** http://pvs.kcc.hawaii.edu/navigate/stars.html

2. **Penn Museum of Archaeology and Anthropology: The Sidereal Compass.** http://www.museum.upenn.edu/Navigation/sidereal/sidereal.html

See pp. 14-15 for more info.

Nainoa Thompson's Hawaiian Star Compass

Compass Names

Many Polynesian groups use the sidereal compass; however, the names of the points, houses, constellations, and stars change according to the group's language. For example, the 32 houses on the Hawaiian star compass have traditional Hawaiian names. The names of the 4 cardinal directions are:

'Akau (North) **Hikina** (East) **Hema** (South) **Komohana** (West)

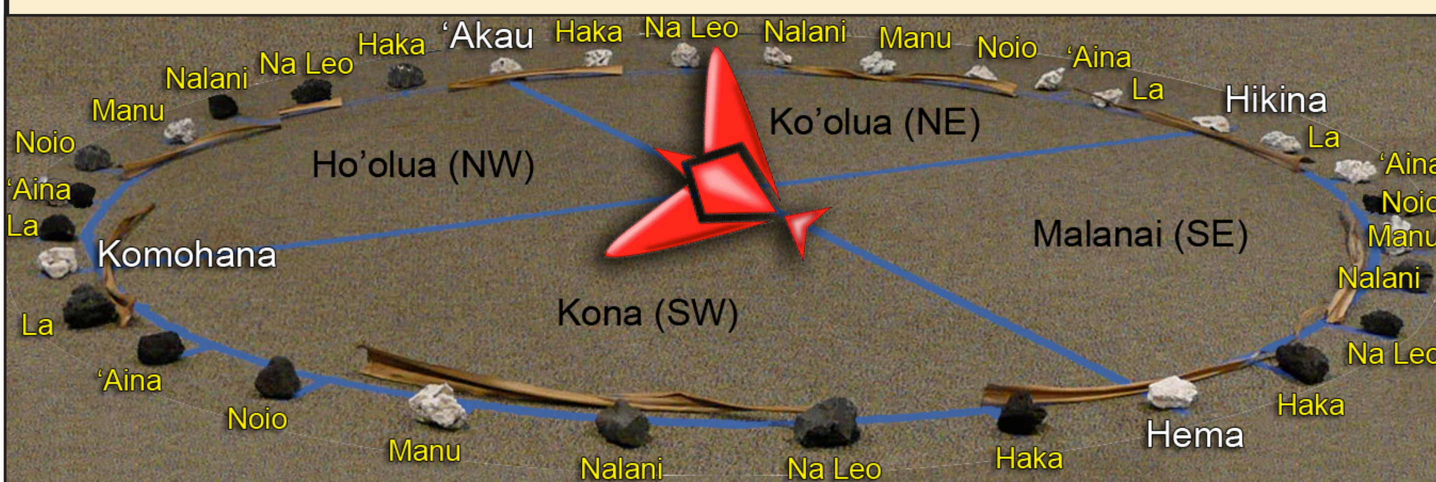
The 4 cardinal directional points divide the 360º compass (circle) into 4 quadrants. These quadrants have been given names associated with the wind directions.

Ko'olau (NE quadrant) **Malanai** (SE quadrant) **Kona** (SW quadrant) **Ho'olua** (NW quadrant)

Each quadrant is divided into 7 directional points and houses. The 7 directional houses in each quadrant combine to give 28 compass directions. These 28 compass directions plus the 4 cardinal points make up the 32 points (or bearings) of the star compass. See the complete set of names of the cardinal points, quadrants, and houses of the Hawaiian star compass in the picture below.

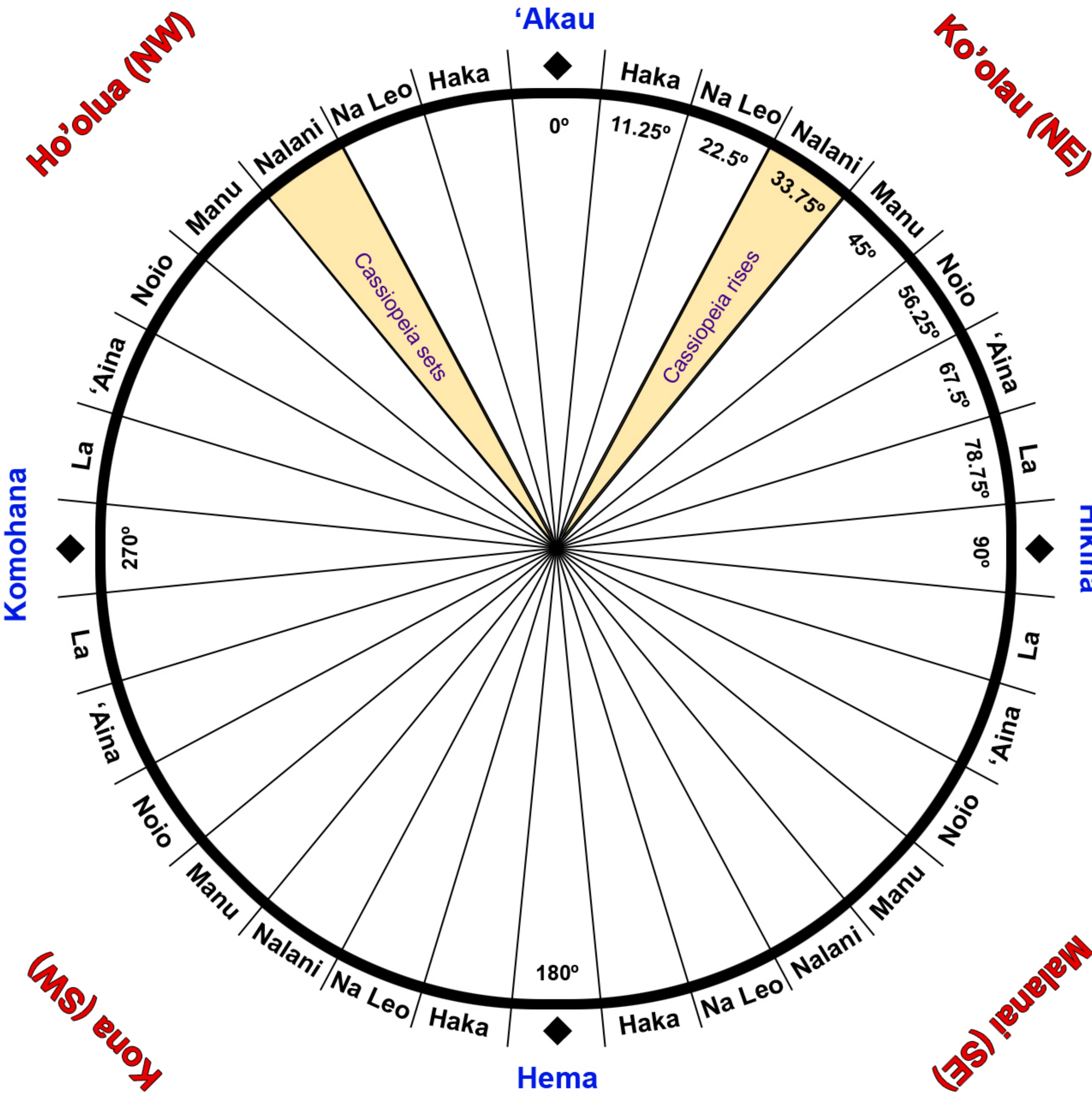
Tracking the Stars

A star that rises in a house on the NE horizon travels across the sky and sets in a house of the *same name* on the NW horizon. Thus, the rising and setting points of the stars are clues to direction. For example, constellation Cassiopeia rises in the house of Nalani in the NE quadrant and sets in the house of Nalani in the NW quadrant. Likewise, the star Antares rises in the house of Manu in the SE quadrant and sets in the house of Manu in the SW quadrant. In addition to tracking stars, navigators use the star compass to align their canoe in the direction they wish to travel much like a bird aligns itself on its course of flight. This is illustrated in the image below.



Students can construct a star compass in the classroom using painter's tape and rocks or shells!

Hawaiian Star Compass

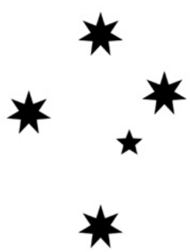


The Penn Museum of Archaeology and Anthropology has a web site that illustrates the sidereal (star) compass with a nice animation: http://www.museum.upenn.edu/Navigation/sidereal/sidereal.html

2. Night Sky (planets, stars, and meridian pairs)

The Polynesians and other seafarers of the Pacific could read the night sky like a road map. One of their techniques involved setting a course toward a star that they knew rose or set on the horizon in the direction of their destination. Throughout the night, these navigators also checked other star alignments to make sure that they were on course. If their heading was wrong, the heavens showed them how to correct it.

Orion (constellation) and Betelgeuse (star)



Southern Cross

A bright constellation in the southern hemisphere known as the Southern Cross helps a navigator to locate the South Pole. Farther north, in the northern hemisphere, a sailor can continuously take bearings from Polaris—the North Star—which appears to be almost directly above the North Pole. The Big Dipper (Ursa Major) is an important northern hemisphere constellation because the two outermost stars of the "dipper" point to the "tip of the handle" of the LIttle Dipper (Ursa Minor), which is the star Polaris. Other popular wayfaring stars in the northern hemisphere include the constellations Cassiopeia, Sagittarius, Scorpius, and Orion and the stars Vega, Altair, Antares, and Betelgeuse (which lies at a right angle above Orion's belt). The altitude of "meridian pairs," which are two stars that pass through the same line of longitude at the same time, can be used to determine one's latitude (one's north/south geographic position). Furthermore, the planets Venus, Mars, Jupiter, and Saturn are also bright enough to use in celestial navigation when they are present in the night sky. So on a clear night, sailors on all seas can check their heading by means of at least one celestial reference.

Little Dipper
& North Star

The Nautical Almanac, which was first published in the mid-1700s, is a tool that describes the positions and movements of celestial bodies, therefore enabling navigators to use celestial navigation to determine the position of their vessel. The Sun, Moon, planets, and 57 stars–chosen for their ease of identification and wide spacing–are included in the almanac, which specifies for each whole hour of the year the position on the Earth's surface at which each of these bodies is directly overhead. The Sun, Moon, and planets 'move' independently and so are specified separately; however, for the stars only Aries is specified because the other stars have a set angular distance from Aries. The navigator can use difference tables to extrapolate the position of each object for each minute of time. Although, Nautical Almanacs were not available to the ancient Polynesians, it must be noted that Polynesians and other mariners from earlier times passed on much of this kind of information verbally, from generation to generation.

Read more about the 57 navigational stars at: http://en.wikipedia.org/wiki/Navigational_stars

*** * * * * Educational Technology – Check it Out! * * * * ***

- Learn to navigate! This web site offers an ***educational animated tutorial*** on how to identify 3 constellations (Orion, Big Dipper, and Cassiopeia), 2 stars (Polaris and Betelgeuse), and 1 planet (Jupiter) in the night sky. http://www.quietbay.net/Science/astronomy/nightsky/

- Learn to find North and South! This web site has ***good illustrations*** showing how to use stars and constellations in the northern and southern hemispheres to determine the directions of north and south. http://adventure.howstuffworks.com/true-north3.htm

3. Winds

The direction of the wind can be used to hold a course by simply holding the wind at a constant bearing to the sailing vessel. However, the wind may change direction during the day so its direction must be checked frequently against rising or setting celestial bodies and the ocean swells.

The prevailing winds are the winds which blow quite frequently over a certain region of the earth. These winds are the causes of waves as they push the ocean, and they often show global patterns of movement in the earth's atmosphere. Winds form as hot and cold air masses move from areas of high pressure to areas of low pressure in effort to equalize. The prevailing winds change direction with latitude due to the changes in air pressure and the earth's temperature, which is warmer at the equator and colder toward the poles.

The prevailing surface winds are calm at the equator in a region known as the doldrums. North of the equator, the winds blow from the northeast and are called the trade winds. Around 30 degrees north, near the tropics, the winds calm again in the horse latitudes. Winds blowing toward these middle latitudes are called the prevailing westerlies. Then, around 60º north, the winds shift again into a pattern known as the polar easterlies as cold heavy air moves toward the warmer latitudes. This same pattern is mirrored in the southern hemisphere.

View a map of the prevailing winds at:
http://maps.howstuffworks.com/world-prevailing-winds-map.htm

Polynesian canoe sail

Canoe Speed

The navigator must also monitor the speed of the canoe, which is done on an hourly basis. One method of determining the hull's speed is to watch the white foam of a breaking wave float by the side of the canoe.

A canoe travels at a rate of one third the speed of the wind. For example, if the wind is blowing at 15 knots, then the canoe can travel at a speed of 5 knots because 5 is one third of 15.

Wind direction is also important because a canoe can only travel in certain directions toward the wind in order to make use of its sails.

4. Clouds

Clouds often signal land and can be used by mariners to forecast weather. Clouds form over land, so a navigator sighting clouds piled high in the sky can follow it to the land underneath. Clouds that appear motionless could be hovering over a mountain, whereas greenish clouds may be reflecting an island lagoon.

In the vast Pacific Ocean, a navigator must be aware of weather patterns for both the northern and southern hemispheres. Navigators can observe the shape and position of the clouds to forecast weather changes. Low-lying cumulous clouds indicate fair and stable conditions. High clouds that appear to be moving toward the boat indicate a change in weather, so upon seeing them, the crew will prepare for stormy conditions. When planning long ocean voyages, it is best to take into account recurring storm seasons. For the Polynesians, the Pacific typhoon season is one to avoid, typically May through November. Therefore, the preferred time of year for conducting a voyage is in the late winter and spring months.

Cumulus clouds usually mean fair weather

Wayfarers avoid cyclone and typhoon seasons

Clouds forming over island mountaintop in Bora Bora

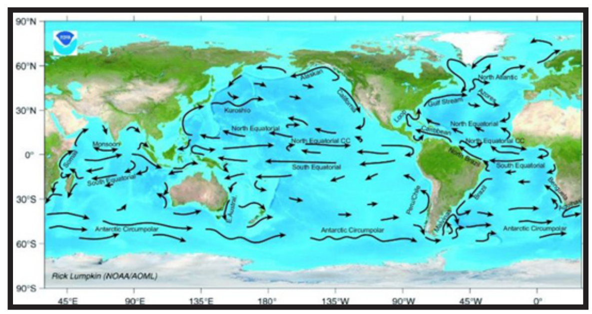
5. Ocean Swells and Currents

Swells are waves that have traveled beyond the winds or storms that generated them. An experienced navigator senses their subtle roll through the hull of the canoe and determines which direction the swells are traveling. Then the navigator tracks the orientation of the canoe in relation to the path of the swells. Unlike other wayfinding signs that appear only by day or night, swells are almost always present. They are most important to the navigator at midday, when other clues about direction are few.

Ocean swells

In addition to providing wayfinding signs, the natural energy from swells can help propel a canoe through the water. If a navigator discovers a swell that is indeed heading in “the right direction” based on other observations (Sun, Moon, stars, clouds, etc.), then the boat is steered to ride the swells providing additional power to the destination.

In regard to ocean currents, these must be calculated ***before*** embarking on the voyage. It is difficult to monitor current drift at sea without instrumentation, so the navigator must precalculate drift for what oceanographers have determined to be the average hourly current set per day. In planning a voyage, the navigator will pre-estimate how many days the crew will be at sea, will factor in current, and then will steer a course that is slightly in the direction of where the current is flowing from in order to negate its net effect. The “doldrums” exist in the northern hemisphere and migrate with the warm water between 3º N and 9º N latitude. In the doldrums, the current reverses its westerly direction and pushes east before transitioning to the equatorial current.



Ocean surface currents

6. Seamarks

Birds headed out to sea to fish

A wayfinder looks for signs to let him know the proximity and direction of land even when he cannot see it. Imagine getting directions from drifting wood or schools of fish. To a navigator, these seamarks are signs that a canoe is headed for land. Drifting seaweed, debris, leaves, and other plant materials can signal land nearby as can clouds piled over islands. Even the ocean can be a seamark. Close to land, waters become calmer and ocean swells change direction.

The diurnal flights of certain birds are the most useful signs for finding landfall since their flights to and from an island gives a fairly specific direction to the wayfinder. As the birds leave an island in the morning to fish, the wayfinder can sail in the direction the birds are coming from to locate land. Likewise, as the birds return to an island in the late afternoon to rest, the wayfinder can follow the birds home. Two of the most reliable birds in the Pacific Ocean include the manu-o-Ku and the noio, which have a flying radius of about 120 miles and 40 miles respectively.

Stingray and school of fish

Micronesians of the Western Pacific, with their long tradition of seafaring between islands, use living seamarks called "aimers." Aimers are commonly encountered sea life between islands and atolls (i.e., a tan shark making lazy movements, a ray with a red spot behind the eyes, a lone noisy bird, a swimming swordfish). If a navigator loses bearings, then the crew is instructed to look for a specific aimer corresponding to that particular route or present location. One does not sail to find aimers; rather one encounters them only when lost and not always then. Aimers serve as a last recourse for the navigator who has missed his landfall or lost his bearings, enabling him to "align" himself once more in the island world.

White tern (manu-o-Ku) with fish

7. Landmarks

Top of Mauna Kea on Hawai'i island

Landmarks are any recognizable geological feature found along an ocean voyage. Common landmarks could include islands, cays (small islands), atolls, reefs, and submerged rock formations. Smaller landmarks are more visible, and therefore more useful, during daylight hours. While leaving an island for the open ocean, the navigator backsights on the island, lining up two landmarks (e.g. a hill and a mountain) to hold his desired direction. One can also navigate by knowing the shape of reefs or underwater topography which can be seen from the surface.

On long ocean voyages, such as traveling from Hawai'i to Rapa Nui, the navigator should plan to stop at other island clusters along the way in order to restock provisions for the crew. However, these stops are usually kept to a minimum in the interest of not prolonging the overall voyage. There are so many islands in the South Pacific that a crew could be out at sea for years if they stopped at all islands enroute to a final destination. Generally, a crew can supply itself with 30 days worth of meals consisting of preserved, dehydrated, and (for the modern-day wayfarer) canned foods as well as a half gallon of water per crew member per day. Occasionally a crew may need to make stops due to weather, repairs, or emergencies, but often these issues can be handled at sea.

Credits and Sources

The information in this section (pp. 13–20) is attributed to the following Internet resources.

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- Unknown source. Astronomy. *Nightsky*. Retrieved October 2008 from http://www.quietbay.net/Science/astronomy/nightsky/

Additional Resources

The following books can serve as supplemental material for the classroom.

- "An Ocean in Mind" by Will Kyselka
- "Coyote Places the Stars" by Harriet Peck Taylor
- "How the Stars Fell into the Sky: A Navajo Legend" by Jerrie Oughton
- "On the Road of the Winds: An Archaeological History of the Pacific Islands before European Contact" by Patrick Kirch
- "Sailing in the Wake of the Ancestors: Reviving Polynesian Voyaging" by Ben Finney
- "Voyage of Rediscovery: A Cultural Odyssey through Polynesia" by Ben Finney
- "We, the Navigators: The Ancient Art of Landfinding in the Pacific" by David Lewis

Ho'ohana (How)

Driving Question:

Challenge:
Work as a team to navigate an ocean canoe over 5,000 miles from the Big Island of Hawai'i to Rapa Nui (Easter Island). As part of this task, you will need to:

- Plan a route from your starting point (Hawai'i) to your destination (Rapa Nui).
- Be able to determine your location in the ocean (establish a frame of reference) and hold a course to your destination.
- Locate your destination (Rapa Nui).

Constraints:
In planning your voyage, you will ***not*** be able to:

- Use a Global Positioning Satellite (GPS)
- Use a magnetic compass
- Use a radio or satellite phone
- Travel in a straight line

Pahoehoe lava on Big Island Hawai'i

Moai statues on Rapa Nui

Polynesian Triangle in the Pacific Ocean

For guidance on the deliverable, see sample navigation plan on page 28.

Deliverable:
In order to accommodate all participating classes, each class should submit ***one*** navigation plan to NASA Quest. Although students may work in teams and develop more than one solution to this task, the class should choose the best navigation plan to submit. This plan should include:

- Explanatory text describing planned voyage and means of navigation (template on p.29)
- Visual representation of selected method(s) of navigation (Be creative! Suggestions include: collage of tools, star chart, drawing of vessel, chart of wind patterns or ocean currents, etc.)
- Map of planned ocean route (template on p.30)

Submit to NASA Quest via email or regular mail:

Email: Linda.B.Conrad@nasa.gov

Mail: Quest Navigation Challenge
c/o Linda Conrad
NASA Ames Research Center
Mailstop 226-4
Moffett Field, CA 94035

Considerations:
Students should consider the following while planning their voyage.

- Hawai'i's coordinates are 20º N latitude, 155º W longitude.
- Rapa Nui's coordinates are 27º S latitude, 109º W longitude.
- Each degree of latitude represents 60 nautical miles. At the equator, each degree of longitude also represents 60 nautical miles; however, this measurement gradually decreases to zero as the meridians converge at the poles.
- Expected length of voyage (days/ weeks/ months)
- Time of year based on typhoon season and weather patterns in the Pacific Ocean
- The direction and speed of the trade winds and prevailing winds in the northern and southern hemispheres
- The direction of the ocean currents in the northern and southern hemispheres
- The location of other islands that could be used as waypoints for safe harbor or for acquiring provisions
- Location of celestial objects based on time of year and hemisphere

"[The navigator] never sleeps when he's navigating. He says his eyes are closed but inside he's not. Somehow he rests enough to take care of the fatigue and he maintains his orientation."

"The Wayfinder: The 1980 Voyage Home"
by Nainoa Thompson, with Will Kyselka.

In addition to posing the "considerations" on page 23, discuss with students the steps that must be taken to prepare for a voyage. (The checklist below comes from the 'Imiloa Astronomy Center of Hawaii's *Voyages of Discovery* exhibit.) Then, share with students the navigator's journal entry on page 25.

Planning a Voyage: A Navigator's Checklist

- Choose a destination.
- Observe weather patterns and choose a time of year to travel.
- Plot the course.
- Plan navigation strategies.
- Prepare the canoe.
- Select and train a crew.
- Gather provisions (food, water, equipment, etc.)
- Under sail: Keep track of the canoe's course at all times.
- Having reached the vicinity of the destination: Locate land!

Helpful Hint: Visit the U.S. Naval Observatory web site or the Heavens Above web site to get Sun and Moon data for any date and location around the world!

- http://aa.usno.navy.mil/data/docs/RS_OneDay.php
- http://www.heavens-above.com/

Journal of a Navigator

Below is an excerpt from Will Kyselka's *Ocean in Mind*, which captures Navigator Nainoa Thompson's account of the 1980 voyage from Tahiti to Hawai'i. This excerpt describes the departure of Hokule'a, the Polynesian canoe, on May 13, 1980.

Sunrise on the cliffs of Matavai Bay at Point Venus. Each morning for five days we've been watching for the wind. But... the wind has not yet been ready to grace the sails and allow Hokule'a to glide along sea roads traveled by explorers of old. ***We've been waiting for a straight wind, a wind to depart on.*** *Today we have that wind. It's not an ideal wind but it is one that we'll depart on.*

It's late afternoon when we depart Tahiti. A ceremony once again affirms the bond between Polynesian peoples and sends us on our way. ***The setting sun is casting its last rays on high clouds as we leave Tahiti behind in SW Na Leo. Soon the first stars appear and the heavens demand our attention.*** *Thoughts of the hospitality of our Tahitian friends and family are put away and we are left with only ourselves and our memories.*

The Southern Cross is now high in the sky behind us. Each night for the next three or four weeks we'll see it slightly lower, and by the time we reach Hawai'i it will be at the horizon. It will be ten days yet before we'll see the North Star. During the next few hours the tiny island of Teti'aroa will be moving along our star compass from 'Akau to Hema as we pass close to it.

The first dawning of light is the important time for the navigator. It is the time for judging the sea and swells relative to the positions of the stars, a time for the reading of the weather for the day. *Light creates the day and the colors in the clouds and in the mists in the salt air. Mau has internalized countless sunrises, so he knows how to read the weather and when it is right to sail. For him this knowledge is the means of survival of his island's people. For us this canoe is our way of understanding the people of old.*

Navigating without instruments is a personal act. You must know the principles but you cannot reduce wayfinding to a set of formal operations. *I'm constantly discovering new things that are useful in getting the canoe there... Like knowing where the moon is: One night it was really cloudy. It was nearly a Full Moon but clouds were so thick you couldn't see it. Still I knew where it was even though there was no reason for me to know. I could have figured it out analytically, but I already knew. Here's a separation between knowledge and understanding. At times like that I know, but I don't know how I know.*

Credit:

Polynesian Voyaging Society. Voyages. "1980: Hawai'i to Tahiti and Back." *The Wayfinder: The 1980 Voyage Home* by Nainoa Thompson with Will Kyselka. Retrieved October 2008 from http://pvs.kcc.hawaii.edu/nainoa80return.html

Hawai'i

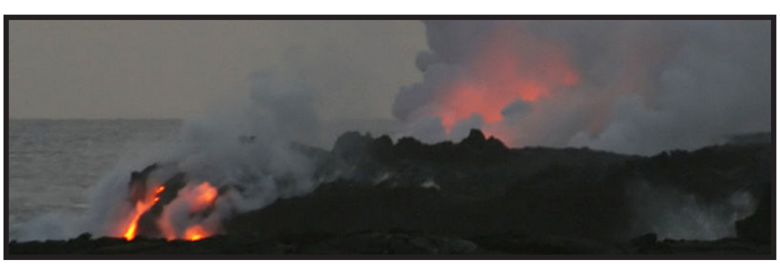
Hawai'i, also known as the Big Island, is the largest island of the Hawaiian island chain and is bigger than the other seven Hawaiian islands combined. It has a land area of 4,028 square miles, which is roughly 64 times the size of Rapa Nui. Hawai'i lies 3,200 kilometers (1,988 miles) southwest of the North American mainland, and it is the southernmost point of the United States.

Hawai'i is a volcanic island consisting of five shield volcanoes originating from a hotspot on the ocean floor. Two of the volcanoes on Hawai'i are still active: Mauna Loa and Kilauea. Kilauea, which has been erupting since 1983, continues to add land to the island via its lava flows. Mauna Kea, the island's most prominent volcano, is the tallest mountain in the world, measuring 33,476 feet. Even though it only measures 13,796 feet above sea level, it surpasses the height of Mt. Everest when measured from its base at the sea floor.

Being isolated and volcanic in origin, it is supposed that life was first introduced to the Hawaiian islands by "wind, waves, and wings" (birds). Humans are believed to have arrived at the islands about 1,500 years ago between the fourth and sixth centuries, traveling from the Marquesas and the islands of Tahiti. European discovery occurred several centuries later in 1778 when Captain James Cook arrived and dubbed the archipelago the Sandwich Islands. After becoming a U.S. Territory in 1898, the Hawaiian islands were declared the 50th member of the United States in 1959. The name of the Big Island, Hawai'i, is thought to have originated from either "Hawai'iloa," a legendary Polynesian navigator, or from "Hawaiki," the legendary realm from which Polynesians originated and to where they return in the afterlife.

Learn more about Hawaii at:

- Polynesian Culture Center: http://www.polynesia.com/hawaii/introduction.html
- Wikipedia: http://en.wikipedia.org/wiki/Hawaii_Island



Rapa Nui

Rapa Nui, also named Easter Island by a Dutch explorer who discovered the island on Easter Sunday 1722, is one of the world's most isolated inhabited islands. It lies 3,600 kilometers (2,237 miles) west of South America and became a special territory of Chile in 1888. Like Hawai'i, Rapa Nui is a volcanic island brought about by a hotspot in the ocean floor. The island formed about 750,000 years ago, but it has not been volcanically active for over 100,000 years. Much of the history of this small 63 square mile island was lost due to the quick demise of nearly 97% of the population in the mid-1800s. Disease, enslavement, and invasions all but obliterated the island's population during a ten year period, resulting in the loss of much of the knowledge of the island's past civilizations. Less than 4,000 people inhabit the island today.

In addition to the near-destruction of its people, Rapa Nui also expereinced destruction of its native ecosystem. Agricultural practices and possibly climate changes led to the deforestation of the island, which is now primarily covered in grassland.

The most popular aspect of the island is the mysterious Moai statues dating back thousands of years. Around 887 Moai have been inventoried, and these statues represent chiefs or important people of the tribes. Although often only the heads of the statues are visible, they are actually complete torsos that have been buried over time by shifting soil. The giant Moai were carved with hand chisels out of volcanic rock, and many remain in the quarry unfinished. The largest Moai, known as Paro, weighs 82 metric tons (180,779 pounds). It is speculated that it would take between 180–250 men to move a single statue.

Moai

In 1986, the landing strip at the Rapa Nui airport was lengthened by NASA to cover the full width of the island. This made it possible for the Space Shuttle to land at Rapa Nui in case of emergency.

Learn more about Rapa Nui at:

- Polynesian Culture Center: http://www.polynesia.com/rapa-nui/introduction.html
- Wikipedia: http://en.wikipedia.org/wiki/Rapa_nui

*** Sample Navigation Plan ***

Challenge I: Tahiti to O'ahu

How will you stay on course?

Crew Name: Team Quest

Vessel Name: Hokule'a

Date/season of embarkation: evening of May 13, 1980   (late spring)

Distance of voyage (Nm): 2,460 Nm

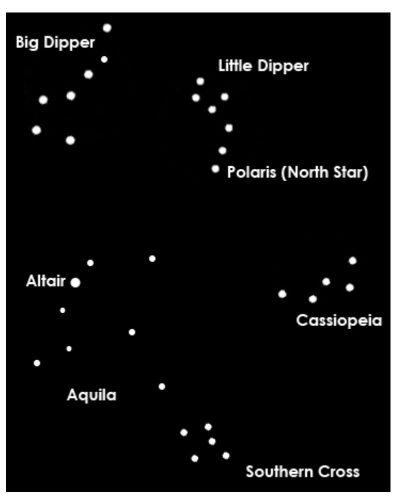
Expected length of journey: 20–30 days (3–4 weeks) traveling an *average* rate of 100 Nm per 24-hr period

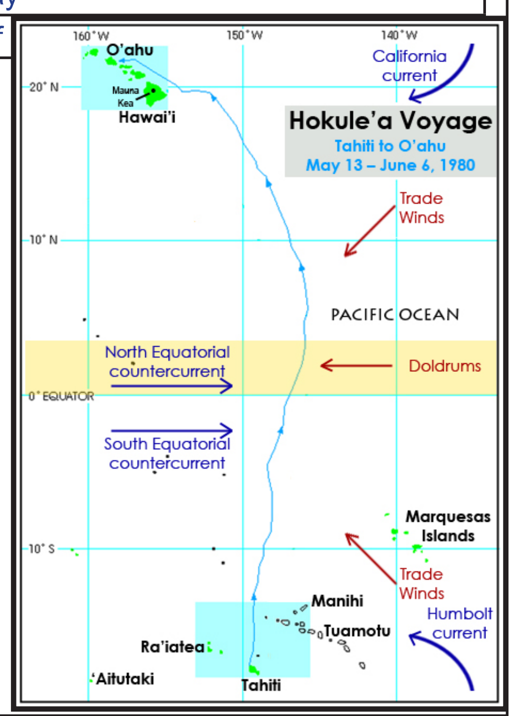
General description of route:

Latitude	Longitude	Direction	Distance	Navigational Signs
17º S	149º W	'Akau (N)	240 Nm	North shore Tahiti, setting Southern Cross, 1% waning crescent Moon setting early evening (New Moon)
13º S	149º W	Haka (NE)	300 Nm	Rising Little Dipper (night), waxing crescent Moon (day)
8º S	148º W	'Akau (N)	180 Nm	Setting Southern Cross (night), 32% waxing Moon (day)
5º S	148º W	Na Leo (NE)	540 Nm	Rising Big Dipper (night), 50% waxing Moon (day/night)
4º N	146º W	'Akau (N)	240 Nm	North Star (Polaris), 91% waxing Moon (day/night)
8º N	146º W	Na Leo (NW)	360 Nm	Setting Big Dipper, Full Moon (night)
14º N	148º W	Nalani (NW)	300 Nm	Setting Cassiopeia, 96% waning Moon (night)
19º N	152º W	La (NW)	120 Nm	Mauna Kea on Hawai'i (day), 80% waning Moon (night)
20º N	154º W	Noio (NW)	120 Nm	NE coast Hawaiian island chain (day), 63%Moon (night)
21º N	156º W	Komohana (W)	60 Nm	East shore of O'ahu & setting Altair, 41% waning crescent Moon setting midday
21º N	157º W	-	-	Arrive east shore of

Methods of navigation:

- Day:
  - Sun and Moon (May 13 - 20)
  - Ocean swells
  - Landmarks: Mauna Kea
- Night:
  - Moon (May 21 - June 6)
  - Stars: Polaris, Altair
  - Constellations: Big Dipper, Little Dipper, Cassiopeia, Southern Cross
- Winds (marked in red on map)
- Currents (marked in blue on map)





Other considerations:

- No planned stops will be made because the journey is expected to last less than 30 days.

Challenge I: Hawai'i to Rapa Nui

How will you stay on course?

Crew Name: ______________________________

Vessel Name: ______________________________

Date/season of embarkation: ____________________

Distance of voyage in nautical miles: ____________________

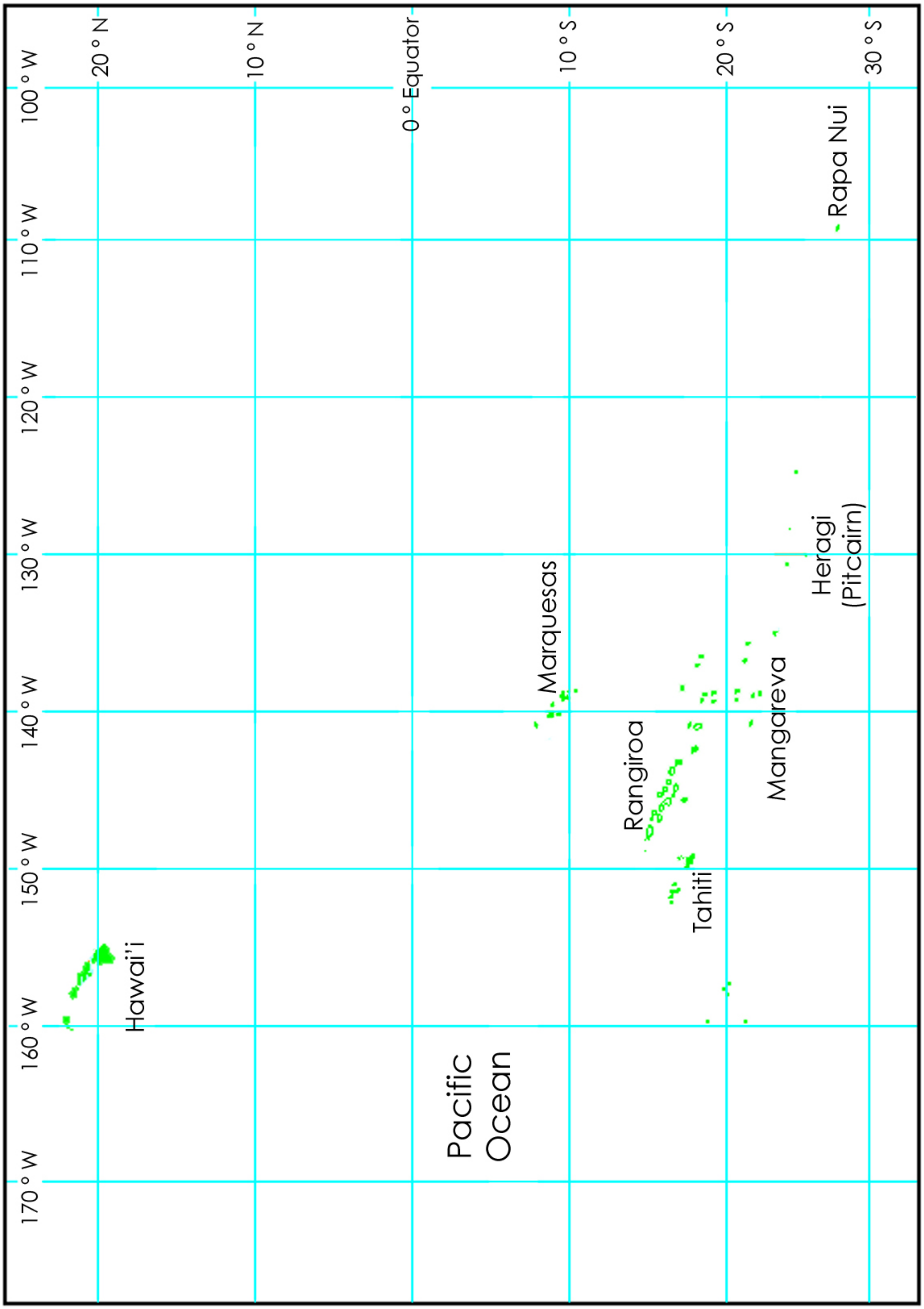
Expected length of journey: ________________________

General description of route:

Methods of navigation:

Other considerations:

Navigation Plan Map: Hawai'i to Rapa Nui



Ho'opuka (If)

Driving Question:

Discuss with students the possibilities of how they can use and extend their new-found knowledge about navigating the sea without modern instrumentation.

- Have you ever been lost in your city or perhaps while taking a hike? How could you use traditional navigation methods to find your way?
- Why learn the traditional navigation methods when newer, more accurate navigation instruments exist?
- If you were to create a new navigation method, what would it be?
- Using your newly-acquired wayfinding skills, what destination might you choose to explore here on Earth?
- What destination might you choose to explore beyond Earth?

  (In Part II of the Challenge, students will learn about space navigation and then devise a plan for navigating an unmanned spacecraft from Earth to the Moon, much like the upcoming LCROSS mission. This Challenge will begin in the early 2009.)
- How would navigating in space be different than navigating on Earth's land and sea?
- What methods of navigation might be needed outside our planet?