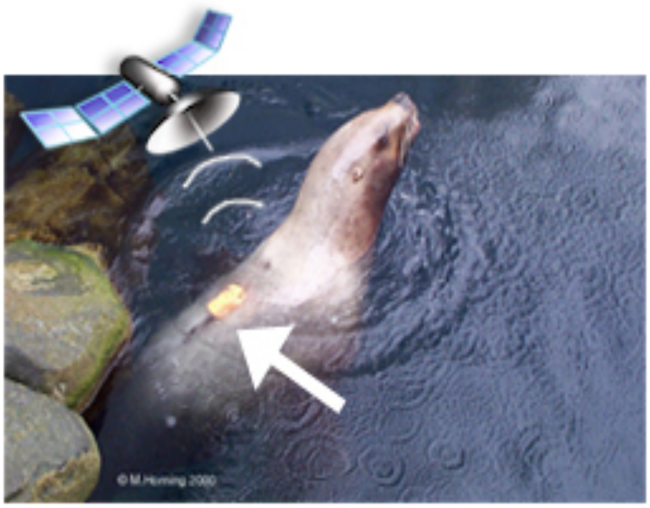
Engineering Solutions for Sea Lion Research

A Marine Science and Engineering Curriculum

Grades 6 – 12



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A Marine Science and Engineering Curriculum for Grades 6-12
Version 2.0

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Project Director: Dr. William Hanshumaker, Oregon State University

Acknowledgments

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Purpose for Curriculum

In 1998, Oregon State University researcher, Dr. Markus Horning was flying above the Aleutian Islands in Alaska, looking for Steller sea lions. Where they were once as many as rocks on a beach, he noticed just a few lonely males on the shore. He wondered about why the population had declined and how he would find the answer. Dr. Horning eventually partnered with an engineer to design a device, the Life History Transmitter, that could help him answer his research questions.

Science, engineering, and technology often work together to lead to new innovations. However, many students have little idea of how these topics relate to one another, and "they do not clearly understand what engineers do and how engineers and scientists work together to create technology." [1]

The exciting world of sea lion research that forms the basis of this curriculum provides an ideal framework for students to learn more about the principles of marine science and engineering and how they work together to create tools that scientists use. Through a variety of hands-on activities, this curriculum explores physical science concepts in the context of the Life History Transmitter Project. This curriculum uses science-as-inquiry methods and engineering design projects to teach students about telemetry or remote sensing (technology), the biology and ecology of sea lions and the Alaska ecosystem, the challenges of marine research in a remote environment, and how engineers develop solutions to science problems. Also covered are the connections between populations, resources, and environments; the risks and benefits of technology; and technology and society.

This curriculum is intended for teachers of grades 6-8 and 9-12 seeking to incorporate science, technology, and engineering into their classroom. Because this curriculum is based on an integrated research project, teachers can use this sequentially as an entire science and technology unit or select from individual activities and materials. Each activity can be used as stand-alone lesson and is designed in 50-minute intervals suitable for classroom use. Correlation of the curriculum content to National Science Education Standards and Ocean Literacy Principles is included with each activity.

Lesson 1: Population Ecology of the Steller Sea Lion

ENGINEERING DESIGN CHALLENGE:

To understand what is happening with Steller sea lion populations, the Life History Transmitter (LHX) must detect mortality events in all situations and places.

FOCUS

Population ecology, density effects, anthropogenic effects, risks and benefits

GRADE LEVEL

6 - 8

FOCUS QUESTIONS

- How do scientists study population declines and mortality?
- What are the causes of death (mortality) in Steller sea lions?
- Are those causes natural or man-made?
- How do the causes of death relate to the number of animals and human population size?

LEARNING OBJECTIVES

Students will:

- calculate the rate of decline using aerial survey photos of Steller sea lions;
- describe the difference between Mark-Recapture and the LHX technology;
- research the causes of mortality in Steller sea lions; and
- engage in a discussion of how/whether these factors change with population density (older grades).

MATERIALS

- Print out aerial survey photos (high resolution photos available at http://www.sealtag.org/Resources.html); You may want to laminate for future use.
- Mark/Recapture simulation: http://www.biologycorner.com/flash/mark_recap.swf or sack of dry, white beans and pencils or permanent markers
- Mark/Recapture Table
- Rulers
- Student access to Internet or library resources

AUDIO VISUAL MATERIALS*

- Computer and projector for the PowerPoint
- PowerPoint http://www.sealtag.org/Resources.html
- Mark/Recapture Table

- Mortality Worksheet & Answer Key
- Internet access for the simulation (*can substitute bean activity)

TEACHING TIME

- Two class periods (100 minutes)

SEATING ARRANGEMENT

- Whole class instruction and small group activities

KEY WORDS

- Population, ecology, mortality, Life History Transmitter, population density, mark-recapture, density dependence, density independence, survival rates, anthropogenic

BACKGROUND INFORMATION

Science as Inquiry

For students to begin the inquiry process, they must first understand the process of science. Science generally begins with an observation or information that leads to a question. For the LHX project this was a simple observation during an aerial survey that there were dramatically less Steller sea lions than in previous decades. This observation led to a question: why are they not there and what is happening to them? The question develops into a hypothesis, a scientific explanation that is specific, testable, and logical. (It is important to remind students that a hypothesis is not a question but a declarative explanation.) For example, for the LHX project scientists developed the hypothesis that young Steller sea lions are preyed upon (eaten by) predators such as sharks and killer whales in such large numbers that too few survive to an age where they can reproduce.

After developing a testable hypothesis, scientists typically study the scientific literature on the subject to be certain the answer is not already published. Next, they determine what data is specifically needed to test their hypothesis. Then they develop a method or use existing methods to collect data and test their explanation. With this idea, they seek funding and any necessary permits. With these in place, they test their hypothesis and publish their results in scientific journal after their methods and analyses undergo peer review. Based on their initial findings or the reviews, scientists may revise their ideas and do more testing if necessary. Although we have presented this as a sequence of events, the science process is not often linear. See this science process flowchart:
http://undsci.berkeley.edu/flowchart_noninteractive.php.
Much of scientists' time is spent reviewing, revising, writing, and speaking about results.

Steller Sea Lion Population Ecology

A population is a group of the same kind of organism living in a defined area, for example, the human population in Oregon. Population ecology refers to the interactions of animals with their environment and how populations change over time. Scientists that study population ecology study the population size or numbers of individuals and what factors influence the size of populations. The number of organisms an ecosystem can support depends on the resources available and other biotic and abiotic factors. Assuming adequate resources and favorable conditions, populations will grow at rapid rates. Resource availability, ocean conditions, and predation as well as other factors limit population growth in the ocean.

Steller sea lions are distributed around the North Pacific rim from the coast of Japan near northern Hokkaido, near Russia in the Kuril Islands and Okhotsk Sea, to the Aleutian Islands in Alaska and central Bering Sea and south along British Columbia and Oregon to Northern California. The population is divided into two distinct segments known as the Western Stock and Eastern Stock. (A stock is a management unit for fishery managers.) This division is based on genetic and physical differences, and, most importantly, population trends of the two stocks.

The population is divided into the two stocks at at 144° West longitude (Cape Suckling, Alaska). The Western Stock includes Steller sea lions that reside in the central and western Gulf of Alaska, Aleutian Islands, as well as those that inhabit the coastal waters and breed in Asia (e.g., Japan and Russia). The Eastern Stock includes sea lions living in southeast Alaska, British Columbia, California, and Oregon.[2]

(Students may find Eastern versus Western stock confusing since we normally think of the West Coast of the U.S. as "west" and Japan as being "east". The easiest way to explain this by pointing out that, when considering the population as a whole, the side closest to the U.S. is the easternmost extent and the side closest to Japan is the westernmost extent of the population.) See: http://www.nmfs.noaa.gov/pr/pdfs/rangemaps/stellersealion.pdf

Between the late 1970's and 2008, the Western stock declined from 160,000 to 42,000. This led to the Western stock being listed as endangered, at risk of extinction under the Endangered Species Act (ESA). The Eastern stock increased from 22,000 to 52,000 between the mid 1970's and 2009. It is listed as threatened (with extinction) under the ESA. Due to the decline of the Western Steller sea lion and the small population of Eastern Steller sea lions, people have been very interested in learning more about what might be causing those population trends. The basic equation that defines a change in population is:

	(Births – Deaths) + (Immigration - Emigration)	
or	(Births – Deaths) + (animals in – animals out)	for younger audiences
or simply	(births-deaths).	

If any part of the equation changes, the population numbers change.

The Life History Transmitter Project focuses on the death or mortality side of the equation. The LHX team of scientists' hypothesis is that predators such as sharks and killer whales prey upon young Steller sea lions in such large numbers that too few survive to an age where they can reproduce. This would cause the population to decrease. In this lesson, students will have an opportunity to research the causes of mortality in Steller sea lions.

"One way to estimate the size of a population is to capture and mark individuals from the population, release them and then resample to see what fraction of individuals carry marks."[3] Mark-recapture is effective for smaller, (closed) populations where there is not much movement in or out of the population. For mark-recapture in Steller sea lions, because they shed their fur each year, the animals are branded. (This is a similar process as branding cattle.) Scientists then go back to the same sites where they did branding to recount the animals. In remote areas, researchers use aerial photography to count animals. Students will use some of these aerial photos to estimate percent decline in the population. Another use for mark-recapture is to determine survival rates. Scientists capture animals, mark and release them, and recount them again after some time, usually the same time of day and year. If they do not see the same marked animal again, they assume the animal is dead. With animals that move a lot in and out of an area and that spend time underwater, this assumption may be wrong. The LHX is designed to work throughout the life of the animal no matter where it may be and gives important information about how the animal died.

Older students may be able to understand the importance of density dependence and populations. In the case of a constant level of predation, the predator has a greater impact on a smaller population versus a larger population. For example, there are 100 sea lions; the killer whale predator eats 10% or 10 sea lions. If the sea lion population is reduced to 10, then 10% is 1 animal. If you assume each animal has 10 offspring during its lifetime. The smaller population will be more affected by predation. Alternatively, factors like pollution's effect on the Steller sea lion population, affect animals in a density independent way.

LEARNING PROCEDURE

Prior to the class period, have students read the website http://www.sealtag.org, especially Population Ecology: http://www.sealtag.org/PopEcology.html and the selected readings. Separate the class into research teams.

Part I. Students learn how researchers use mark-recapture to estimate population size using the online mark-recapture simulation: http://www.biologycorner.com/flash/mark_recap.swf. This exercise can be done as a class. Alternatively this exercise can be done with beans using teams.

1. Have students note the original number of marked rabbits = 10
2. Students count the number of marked, unmarked, and total number or rabbits in each trap.
3. Students fill in their results on their table or teacher puts up on the board.
4. Estimate the population size using the equation below:

$$\text{Population size} = \frac{\text{(number captured) x (number originally marked)}}{\text{(total number captured with mark)}} = \frac{37 \times 10}{9} = 41.1$$

Here are the results students should get on their table:

Trap Number	# Marked	# Unmarked	Total
1	1	3	4
2	1	4	5
3	1	1	2
4	0	3	3
5	1	4	5
6	1	2	3
7	2	2	4
8	1	2	3
9	1	4	5
10	0	3	3
Total number	9	28	37

Researchers also use mark-recapture studies to determine survival rates, the proportion of animals that are alive at the beginning of the year that survive to the end of the year.

Part II. Using the photos and the following equation, have students calculate the percent decline, the percentage that the population has reduced over time, for Steller sea lions. For example, imagine there were 100,000 sea lions in 1970, and there were 50,000 sea lions in 2000. The percent decline is 50%.

Give each team photos of the aerial surveys. Explain that the rate of decline is what has influenced the listing of the Steller sea lion as endangered under the Endangered Species Act. Photo HD was taken in 1983 (Figure 1) below. Photo LD was taken in 2000 (Figure 2) below.

1. Measure the scale bar at the top, and use it to measure out a 15m X 15m square.
2. Count the number of animals in the square in each photo. Students may want to count multiple squares per photo and average the results of each for accuracy.
3. Calculate the area for each square: Area= width x height = 15mX15m = 225m^2
4. Calculate the percent change using: % change = $-(100-(C_2 \times 100)/ C_1)$,
   Where C_1 = the number of counts/ area for year 1
   Where C_2 = the number of counts/area for year 2

For LD, the number of animals is about 64 in a 15 X 15 m square. For HD, the number of animals is about 120 in a 15 X 15 m square. This would yield a change of -46.67% in 17 years. The number is negative since there is a reduction in the number of animals.

Have students engage in a group discussion about the sources of error for this method and list them. Students need to decide whether or not to count animals that they can only partially see in a square. Students can try different techniques and see how it influences the results. For lower grades, students can simply count one or multiple squares on picture and calculate the total number of animals in that area. Aerial surveys allow scientist to estimate numbers of animals without having to recapture them and without having to count each animal in the photo. Taking a smaller sample from a large sample such as counting a smaller box within a larger area is called sub-sampling.

Figure 1: Photo taken in 1983 at location X

Figure 1: Photo taken in 2000 at location X, note that the animals are spaced farther apart so that there are less animals per area.

Part III. Discuss the population decline in Steller sea lions using the graphs in the PowerPoint. Have students brainstorm about what might be the possible causes of the decline/mortality in Steller sea lions. Make a list on the board. Allow students to choose which topic they will research. Students can use websites from the resources section below or www.sealtag.org to find their answers.

Students research their cause/causes of death, and bring a written report for the next class period. Students must be prepared to discuss whether the cause is natural versus anthropogenic (man-made). For example, pollution is man-made. The Mortality Worksheet is provided to facilitate discussion.

For higher grades, once students have helped fill in the table, engage students in a discussion about whether the causes would be the same with a greater number of animals per area or a smaller number of animals per area. Scientists call this 'density-dependence'. For anthropogenic effects, how do greater numbers of humans versus lesser numbers of humans affect the Steller sea lion population (increased collisions with ships/boats, pollution, climate change, native harvest, illegal shooting, etc.)?

Finally, now that the students have listed causes, list possible solutions and consequences of those solutions. Students should understand that solutions come with risks and benefits.

CONNECTIONS TO OTHER SUBJECTS

Mathematics, Geography, English/Language Arts, Biology

EVALUATION

The research report, classroom discussion, and participation provide opportunities for assessment.

RESOURCES

[2] *Office of Protected Resources Steller sea lion page*
http://www.nmfs.noaa.gov/pr/species/mammals/pinnipeds/stellersealion.htm

[3]*Methods of Estimating Population Size*
http://www.sci.sdsu.edu/classes/biology/bio541/anderson/pdf/mark_recap_instructions.pdf

National Marine Mammal Laboratory Marine Mammal Education Web
http://www.afsc.noaa.gov/nmml/education/pinnipeds/Steller.php

The Biology Corner
Online Mark/Recapture Simulation
http://www.biologycorner.com/flash/mark_recap.swf
(If this loads looking like strange language, hit the refresh button on your browser)

Estimating Population Size (with beans)
http://naturalsciences.org/files/documents/enc/TH_Estimating_Population_Size.pdf

NATIONAL SCIENCE EDUCATION STANDARDS

Content Standard A: Science as Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C: Life Science
- Populations and ecosystems

Content Standard E: Science and Technology
- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives
- Populations, resources and environments
- Risks and benefits – background: risks and benefits of using the technology

Content Standard G: History and Nature of Science
- Science as a human endeavor
- Nature of scientific knowledge

OCEAN LITERACY PRINCIPLES

1. The Earth has one big ocean with many features.
5. The earth supports a great diversity of life and ecosystems.
6. The ocean and humans are inextricably connected.
7. The ocean is largely unexplored.

Lesson 2: Animal Crime Scene Investigations: Temperature and Mass

ENGINEERING DESIGN CHALLENGE:

The change in the body temperature captured by the LHX tag informs scientists how the Steller sea lion may have died.

FOCUS

Thermal cooling and heat exchange, how cooling changes with mass, cooling curves

GRADE LEVEL

6 - 8

FOCUS QUESTION

- How does the LHX tag use temperature to determine time and cause of death?
- Which cools faster at the same ambient temperature, a large body or a small body?
- What is the relationship between thermal cooling (heat transfer) and mass?

LEARNING OBJECTIVES

Students will:

- interpret cooling graphs to determine the cause of death for a Steller sea lion;
- observe that objects of a larger mass cool more slowly;
- explain how differences in mass affect thermal cooling rates;
- relate the differences in cooling rates to how LHX works; and
- discover how scientists design experiments to answer specific questions.

MATERIALS

- Temperature Profiles http://www.sealtag.org/images/Temperature_ProfilesFinal.pdf
- PowerPoint http://www.sealtag.org/Resources.html
- Modeling clay
- Thermometers, digital or alcohol thermometers
- Cooler or bucket with water
- Ice
- Digital scale
- Watch or stopwatch

AUDIO/VISUAL MATERIALS

- Computer and projector for the PowerPoint http://www.sealtag.org/Resources.html

TEACHING TIME

- One class period (50 minutes)

SEATING ARRANGMENT

- Whole class instruction and small group activities

KEY WORDS

- Temperature, cooling, cooling rate, mass

Science as Inquiry

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After developing a testable hypothesis, scientists typically study the scientific literature on the subject to be certain the answer is not already published. Next, they determine what data is specifically needed to test their hypothesis. Then they develop a method or use existing methods to collect data and test their explanation. With this idea, they seek funding and any necessary permits. With these in place, they test their hypothesis and publish their results in scientific journal after their methods and analyses undergo peer review. Based on their initial findings or the reviews, scientists may revise their ideas and do more testing if necessary. Although we have presented this as a sequence of events, the science process is not often linear. See this science process flowchart
http://undsci.berkeley.edu/flowchart_noninteractive.php.
Much of scientists' time is spent reviewing, revising, writing, and speaking about results.

Temperature

Temperature is the measurement of how hot or cold an object is. Temperature measurements using a thermometer are indirect. For an alcohol or mercury thermometer, they are based on how liquids expand when they are heated relative to a given scale. Digital thermometers typically use electronic sensors whose electrical properties change with temperature. Heat is a measure of internal energy transferred from one object to another. Heat travels from a higher temperature substance to a lower temperature substance until both have the same temperature (thermal equilibrium). According to Newton's Law of Cooling, the rate of change of the temperature of an object is proportional to the difference between its own temperature and the ambient or outside temperature. In simple terms, this means that a larger temperature difference between and object and its surroundings will result in a higher rate of temperature change. To use a sea lion example, for two dead sea lion bodies of the same size and same internal temperature in water of two different temperatures, the one in the lower temperature water will cool at a faster rate. In addition the relationship between the temperature of the object and the ambient temperature, the mass of an object also influences how much it will cool. Larger masses cool more slowly than smaller masses. All other things being equal, a larger mass contains more energy and thus takes longer to transfer its energy in the form of heat to a lower temperature substance. In this lesson, students examine the cooling rates of different masses of clay in ice water of the same temperature over time. Here, **Cooling rate** can be defined as the **amount of heat lost per unit time, using temperature as an approximation for heat.** Because the cooling rate is affected by an object's mass, the LHX uses this difference in cooling rates to determine the cause of death and the mass of the animal at the time of death.

LEARNING PROCEDURE

Teacher introduces the lesson using the PowerPoint supplied.

Part I: (**Inquiry based on the relationship between thermal cooling and mass**) This will be a hands-on experiment measuring cooling rates of small masses of modeling clay. Discuss the effect of mass on cooling rates. Discuss the scientific process and present how scientists do inquiry. Have students predict which masses will cool faster: larger or smaller masses. Based on their predictions, students will fashion different masses of the same shape out of modeling clay for future testing. Have students determine which shape would be easiest and most consistent for testing (a sphere). Why would you not want to test different shapes (multiple variables)? Explain about testing a single variable at a time.

We suggest using masses of between 50 to 200 grams to allow the results to be collected within one class period. Students must weigh each mass. Students can test their masses to see if their predictions match their hypothesis and discover the relationships between mass and cooling rates. For younger students, we provide worksheets for filling in their results. Older students can graph their results and write up a lab report.

Experimental Procedure:

1. Each student team gets a bucket large enough to accommodate 3 or more masses.
2. Instruct students to fill each bucket with ice and water. Allow time for ice to chill water. Mixture should be water mixed with ice. As long as there is some ice floating in the water, the temperature of the water should be zero degrees Celsius.
3. Have each student in the team make a different mass of the same shape (a sphere/ball) out of modeling clay to test. To ensure they test for only one variable, teams should use different weights of the same shape. For varying weights suggest they use 50, 100, 150 and 200 g weights. They can compare their results with neighbors with different masses.
4. Measure the temperature of the water – it should be near zero degrees Celsius.
5. Insert a thermometer into each clay model – have students pay particular attention to placing the sensitive part of the thermometer as close to the core of the clay mass as possible – see Figures 1 and 2 below.
6. Allow shapes to equilibrate at room temperature for 1 minute or until thermometer reading becomes stable.
7. Measure and record the temperature of the clay model.

8. Place the clay model into the ice-water mixture and start the timer/stopwatch or note time (see Figure 3 below).
9. Measure and record the temperature every 30 seconds for 15 minutes or until the clay model reaches the water temperature. Students should find a way to work as a team and check each of their models at the appropriate time.
10. One student per team records the results. Students graph their results, and present their information to their peers. See Figure 4 for sample results from our own testing.
11. As a class students develop conclusions about the relationship between mass and cooling rates.

Figure 1: The sensor of the digital thermometer is placed at the center core of the clay sphere of 100g, which is cut in half. The cable is wound around the sensor, reducing the direct cooling effect of cold water onto the sensor via the sensor cable. The two halves are then joined.

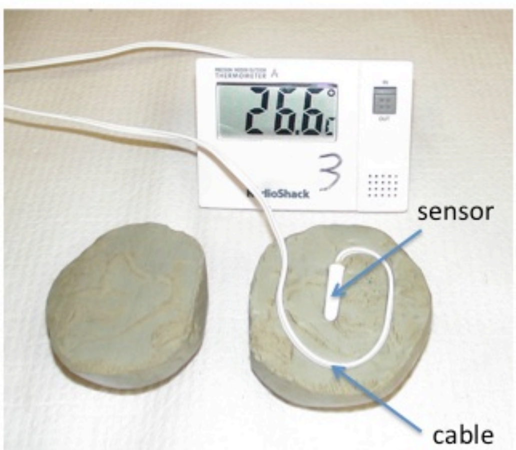
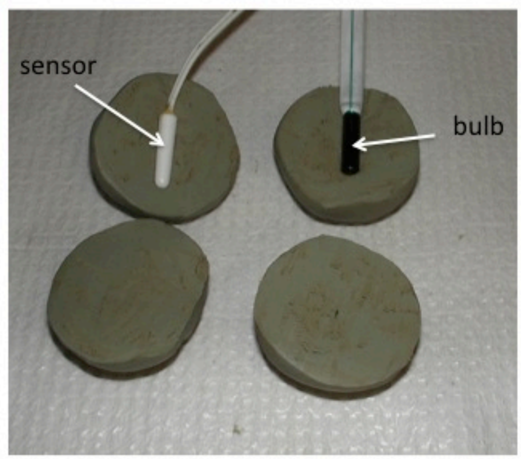


Figure 2: Two smaller 50 gram masses. The left shows the digital thermometer sensor placed at the core, the right one shows an alcohol thermometer placed so that the sensitive bulb is at the core of the clay ball. The halves are then joined.



Dr. Horning's Tips for getting good results in cooling experiments:

1. If possible, use digital thermometers. Alcohol (analog) thermometers will work, but not as well. Plus, they may break resulting in sharp glass shards. Do not use a mercury thermometer because of the safety hazard!
2. You need one thermometer for each clay shape and measurement series. DO NOT pull the thermometer out during one series in order to stick it into another shape and make another measurement. Pulling a thermometer out during a series will result in cold water getting into the core and your results will be off.
3. Measure out the weight of clay, and work it a bit and roll it into a ball.
4. Cut this ball in half.
5. Place the sensitive part of the thermometer at the core of one half of the ball; see Figures 1 and 2 below. For a digital thermometer, the sensitive part is the little nub

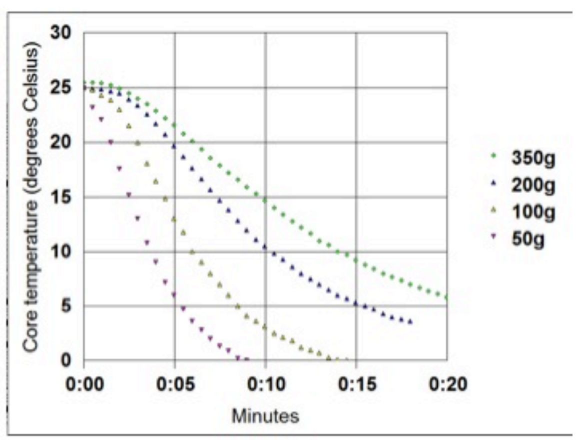
at the end of the sensor cord. For an alcohol thermometer, the sensitive part is the little reservoir bulb at the bottom of the thermometer by the low end of the temperature scale.

6. If using a digital thermometer coil the sensor cable a bit before leading it out of the clay, see Figure 1. This is because the cable also conducts heat away from the core. A short length of cable from core to outside may result in quicker cooling.
7. Press the two halves of the clay ball together. Work them a bit and smooth out the joining edges. Make sure the clay halves are well joined and there is no air between them. This way you have less cold water trickling in to the core, which may change your results.
8. Where the sensor wire or thermometer glass enters the clay ball, pay particular attention to making sure there are no gaps.
9. If you are using an alcohol, analog thermometer, immerse just the clay shape in the ice bath, but try to keep the external glass body of the thermometer out of the water. For a digital thermometer, immerse the clay ball but as little of the sensor cable as possible (see Figure 3).
10. Do not move the clay shape once it is in the water, and do not agitate the water.

Figure 3: A 200 gram spherical clay model is placed in the ice water in a cooler. The mass can be held (suspended) by the sensor cable (shown here) or by the glass body of the thermometer (not shown here).

Expected Results:

Figure 4: **Smaller masses cool quicker**! This graph shows the cooling rates for four different spherical clay masses of 50, 100, 200 and 350 grams, in ice water of zero degrees Celsius. Core temperatures were approximately 25 degrees Celsius at the beginning of the experiment.



Part II: (Match the cooling curve to the cause of death)

Based on their previous experiments, have students use their knowledge of cooling rates to interpret the cooling graphs (curves). Using the temperature profiles from the website, cut out each curve and separate it from the accompanying text below. Provide the PDF profiles of the animals from the Animal CSI page. Have students work in teams or as a class to match the cooling curve to its corresponding text to determine how the sea lion may have died.

CONNECTIONS TO OTHER SUBJECTS

Mathematics, Physics, English/Language Arts, Biology

EVALUATION

The presentation of results and a lab report of the experiment as well as class participation in discussions provide opportunities for evaluation.

EXTENSIONS

Have students try this blubber glove activity to understand how blubber thermally insulates Steller sea lions:

http://www.eece.maine.edu/research/gk12/blubbergloveexperiment.htm.

RESOURCES

Temperature
http://en.wikipedia.org/wiki/Temperature

Inquiry-Based Learning
http://www.neiu.edu/~middle/Modules/science%20mods/amazon%20components/AmazonComponents2.html#components

Teaching Physical Concepts in Oceanography
http://www.tos.org/hands-on/teaching_phys_concepts.pdf

NATIONAL SCIENCE EDUCATION STANDARDS

Content Standard A: Science as Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science
- Transfer of energy

Content Standard E: Science and Technology
- Abilities of technological design
- Understandings about science and technology

Content Standard G: History and Nature of Science
- Science as a human endeavor
- Nature of scientific knowledge

OCEAN LITERACY: ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS

Principle 5. The earth supports a great diversity of life and ecosystems.
Principle 7. The ocean is largely unexplored.

Lesson 3: Buoyancy and Righting Moment

ENGINEERING DESIGN CHALLENGE:

The LHX tag must have optimal buoyancy in order to float to the surface and transmit its signal to a satellite after an animal has died. The tag's antenna must be out of the water in order for its signal to reach a satellite.

FOCUS

Buoyancy, engineering, stable buoyancy (rotational stability), righting moment

GRADE LEVEL

6 – 8

FOCUS QUESTION

- How does the LHX tag float with its antenna above the water?

LEARNING OBJECTIVES

Students will:

- apply the principles of buoyancy to design their own "transmitter";
- examine how engineers develop solutions to human problems including research needs; and
- identify engineering constraints (7^{th})/tradeoffs (8^{th}) for developing their "transmitter".

MATERIALS

- Diagram and picture of the telemetry tag:
  http://www.sealtag.org/images/AM-M229A.1x1-3C%201xPC.LHX.PDF
  http://www.sealtag.org/images/Device.pdf
- 20 oz empty, plastic beverage bottles and lids all of same size/shape
- Buckets for water/sink/aquarium to test buoyancy
- Graduated cylinders (1000 ml)
- Marbles, pennies, washers
- Scale for weighing marbles and pennies
- Handouts: LHX Constraint Table (p. 28)

AUDIO VISUAL MATERIALS

- Computer and projector for the PowerPoint
- PowerPoint http://www.sealtag.org/Resources.html
- LHX CAD Drawing (included as an Adobe PDF file, viewing the file requires an Adobe Acrobat Reader installed on the computer).
  http://www.sealtag.org/images/AM-M229A.1x1-3C%201xPC.LHX.PDF

TEACHING TIME

- Two class periods (100 minutes)

SEATING ARRANGEMENT

- Whole class instruction and small group activities

KEY WORDS

- Buoyancy, engineering, tradeoffs, constraints

BACKGROUND INFORMATION

Buoyancy

When you step into a bathtub with water and notice that you feel much lighter, this is buoyancy. Buoyancy "is a force exerted by a fluid, that opposes an object's weight." [1] This is the force that causes ships to float. On an object in water such as a boat, there are two forces acting on it: the force of gravity and the pressure of the water column below the boat. Since pressure increases with water depth, the pressure below the boat is actually greater than the pressure at the surface. This pressure difference is the buoyancy and is equal to the amount of water the boat displaces. Students may find it confusing that buoyancy does not depend on the weight or shape of the immersed object, only the weight of the displaced fluid. Whether an object will sink or float depends on its density. If it is denser than the surrounding fluid, it sinks. If it is less dense, it floats.

> *(You can demonstrate increasing pressure with depth using a large plastic bag and a bucket. Have students put their arm inside the plastic bag, and then put their arm in the bucket without allowing water into the bag. Students should feel the increase in pressure on their arm.)

In designing objects for use in water, buoyancy is an important factor to consider. Marine engineers consider buoyancy when designing vessels and oil rigs, and engineers designing products for use in the marine environment also consider buoyancy. The Life History Transmitter takes advantage of the principle of buoyancy to free itself from the body and float to the water's surface. Inside the tag, the antenna must float above the surface a certain distance in order transmit its information to a satellite.

Engineering

Engineers use technology to make or design products that serve human needs. In order to create a product many factors go into deciding what engineers will design such as:

- Performance (how well it works)
- Cost
- Safety
- Appearance
- Side effects/environmental impact
- What will happen if the engineering solution fails

- Durability
- Available technology
- Practicality
- Size
- Shape
- Compatibility with other devices
- Stability

Engineering involves designing something to meet a customer's wishes by turning those requirements into testable technical requirements of the product.[1] Generally, the engineer can meet some of those requirements but not all. Each of these factors has tradeoffs. For example, the technology is available, but the costs are high. In addition, to design a product for a specific purpose, the way the product will be used puts certain restrictions or constraints on how the product can be designed in order to work properly for its purpose.

For the Life History Transmitter, there are many design constraints that have to do with the Steller sea lion and its environment. The tag has to be durable to last the lifetime of the animal, including the battery. Since Steller sea lions are diving animals, the tag has to withstand severe pressure. Tags must be small enough to implant inside the animal and prevent the surrounding body tissue from growing onto it, otherwise the tag will not come out of the body. The tag coating must be non-reactive and non-toxic. The tag must also be waterproof in order to survive free-floating in the ocean. Most importantly, in order to transmit its information to a satellite, the tag has to float so that the internal antenna can stick above the water's surface.

"Not only must the tag float, but also it must float at a certain angle and must maintain that angle even when waves start pushing it around. This is something that we call stable buoyancy. Unstable buoyancy is when a small movement of the tag causes it to rotate around wildly. (Students may observe this with their soda bottle transmitter.) A simple example of this would be a ball on a hill and a ball in a trench the shape of a "u". If you slightly move the ball on the hill, it will begin to roll down hill, away from its desired position. If you slightly move the ball in the trench it will continue to roll down hill back to its original position. This is stable buoyancy."[1]

LEARNING PROCEDURE

Have students read the article, *Biology and Ecology of the Steller Sea Lion* to understand what physical and biological factors influenced the design of the LHX provided in the Supplements Folder. Have students list those factors. They can arrive at the factors by listing what kind of environment the Steller sea lions live in and their behavior with the LHX constraint table provided.

Describe the Life History Transmitter project focusing on tag design using the PowerPoint provided. Describe the engineering design process using the resources below. Have students brainstorm about what factors might be important for engineering design. Have students postulate about what criteria and constraints might apply given the biology and lifestyle of Steller sea lions using the LHX Constraint Table.

Constraints of the LHX tag include:

- Appearance: Size, Shape, and Color
- Buoyancy Waterproof
- Able to withstand pressure
- Non-toxic and non-reactive
- Antenna can reach satellite with transmissions.

Students design their own prototype "transmitter" made out of a soda bottle to meet the following design constraints: size, shape (fixed by using a soda bottle), buoyancy, and transmitting abilities of the "antenna". Students are given several bottles for experimenting with various weights inside and no weight. Without weights, the bottles will float but not upright. With proper weighting the bottles will float so that the opening part floats above water. Students must add a given number of marbles or pennies so that five centimeters of the neck of the bottle, representing the antenna, floats above the water's surface. The bottle cannot flip over. Have students plan and write up how they will test their soda bottle transmitter.

Explain that engineers usually start by calculating the specifications of their design. Show students they can calculate how many marbles or pennies they will need by estimating the volume of the soda bottle that remains submerged so that five centimeters are above water.

1. Mark the soda bottle at 5 centimeters below the top with a waterproof marker.
2. Measure the radius (1/2 of the diameter) of the soda bottle using the bottom.
3. Measure the height of the bottle at 5 centimeters below the top
4. Calculate the volume using: Volume = $\pi r^2 h$ or 3.14 x radius x height.
5. Students do a calculation on their bottle.

Because the soda bottle is a complex shape, the volume cannot be determined accurately. Engineers take their calculations to develop a prototype model. Have students perform an experiment to test their initial calculation for their prototype.

6. Fill the bottle with water to the 5 cm below top mark.
7. Pour the water into a graduated cylinder to measure the volume.
8. Explain to students that the density of water is 1g/ml.
9. This volume in milliliters is equivalent to the weight in grams that needs to be added. Have students calculate the grams of weight to be added. Compare the difference between the calculated and experimental values. Have students explain.
10. Have students weigh a penny and a marble, to then calculate how many pennies or marbles need to be added to get the bottle to float correctly.
11. Have students change the amount of weight added to give a different height of the bottle above the water. How does this affect buoyancy?

EVALUATION

The presentation of results and a report of the prototype testing as well as class participation in discussions provide opportunities for evaluation.

EXTENSIONS

Righting moment

Righting moment is a term in naval architecture that refers to the resistance to heeling or tipping. Imagine a sailboat with a large keel. For a buoyant object the upward force acts at the center of the mass of the displaced water whereas the gravitational force acts at the center of the object's mass. If the center of gravity is beneath the center of buoyancy, then the object is stable. If not, the righting moment will oppose the angular displacement.

Have students explore these ideas to understand righting moment.

- How much wax or modeling clay can you add to the top of the bottle, keep it more than five centimeters above the water's surface without flipping over?
- How do ships compensate for a heavy top? (Ships compensate by using water as ballast, a counter weight for the heavy top, or on a sailboat, the keel helps.)
- Ships normally have a hold for carrying fuel, ballast water (for counter weighting) or cargo. What happens when these spaces are empty? (Righting moment is changed and ships can become unstable. Typically, ships are engineered to overcompensate for this.)

The LHX tag uses a heavier plastic container to withstand high pressure. Because the lid is heavy, the batteries compensate for the weight at the top, keeping the LHX from flipping or leaning to the side, just like the weights help keep the bottle from tipping.

CONNECTIONS TO OTHER SUBJECTS

Physics, Mathematics, Biology, English/Language Arts

RESOURCES

[1]Andrew Phan, Oregon State University, by communication.

OPB NOVA Buoyancy Basics
http://www.pbs.org/wgbh/nova/lasalle/buoybasics.html

Engineering is Elementary: Science Engineering and Technology

http://www.mos.org/eie/science_engineering.php

Science Buddies: Free Science Fair Project Ideas, Answers, and Tools for Serious Students

http://www.sciencebuddies.org/science-fair-projects/project_engineering.shtml

Teach Engineering: Resources for K-12 (other great links at bottom of page)

http://www.teachengineering.org/engrdesignprocess.php

What is the 12-step design process?

http://wiki.answers.com/Q/What_is_the_12_step_design_process

NATIONAL SCIENCE EDUCATION STANDARDS

Content Standard B: Physical Science
- Motions and forces

Content Standard E: Science and Technology
- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives
- Risks and benefits
- Science and technology in society

Content Standard G: History and Nature of Science
- Nature of Science

OCEAN LITERACY: ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS

Principle 5: The earth supports a great diversity of life and ecosystems.
Principle 7: The ocean is largely unexplored. *(in background & engineering lesson)*

ENGINEERING IN THE OREGON SCIENCE STANDARDS

5.4 Engineering Design: Engineering design is a process of using science principles to make modifications in the world to meet human needs and aspirations.
5.4D.1 Using science principles describe a solution to a need or problem given criteria and constraints.
5.4D.2 Design and build a prototype of a proposed engineering solution and identify factors such as cost, safety, appearance, environmental impact, and what will happen if the solution fails.
5.4D.3 Explain that inventions may lead to other inventions and once an invention exists, people may think of novel ways of using it.

6.4 Engineering Design: Engineering design is a process of identifying needs, defining problems, developing solutions, and evaluating proposed solutions.
6.4D.1 Define a problem that addresses a need and identify science principles that may be related to possible solutions.
6.4D.2 Design, construct, and test a possible solution to a defined problem using appropriate tools and materials. Evaluate proposed engineering design solutions to the defined problem.
6.4D.3 Describe examples of how engineers have created inventions that address human needs and aspirations.

7.4 Engineering Design: Engineering design is a process of identifying needs, defining problems, identifying constraints, developing solutions, and evaluating proposed solutions.
7.4D.1 Define a problem that addresses a need and identify constraints that may be related to possible solutions.
7.4D.2 Design, construct, and test a possible solution using appropriate tools and materials. Evaluate the proposed solutions to identify how design constraints are addressed.
7.4D.3 Explain how new scientific knowledge can be used to develop new technologies and how new technologies can be used to generate new scientific knowledge.

8.4 Engineering Design: Engineering design is a process of identifying needs, defining problems, identifying design criteria and constraints, developing solutions, and evaluating proposed solutions.
8.4D.1 Define a problem that addresses a need, and using relevant science principles investigate possible solutions given specified criteria, constraints, priorities, and trade-offs.
8.4D.2 Design, construct, and test a proposed engineering design solution and collect relevant data.
Evaluate a proposed design solution in terms of design and performance criteria, constraints, priorities, and trade-offs. Identify possible design improvements.
8.4D.3 Explain how creating a new technology requires considering societal goals, costs, priorities, and trade-offs.

SUPPLEMENTAL MATERIALS LIST

- Aerial-HD (upper photo)
- Aerial-LD (lower photo)
- Mark Recapture Table
- Mortality Worksheet
- Mortality Worksheet Answer Key
- LHX Constraint table

Lesson 4: Electromagnetic Radiation and Shielding

ENGINEERING DESIGN CHALLENGE:

The antenna of the LHX tags must be able to generate an unobstructed signal.

FOCUS

Electromagnetic radiation and shielding, Faraday's cage, engineering constraints, tradeoffs

GRADE LEVEL

9 - 12 (Physical Science & Engineering)

FOCUS QUESTIONS

- Do radio waves propagate through air, water and/or tissue?
- Can LHX transmissions reach a satellite from underwater or inside the body of the sea lion, why or why not?

LEARNING OBJECTIVES

Students will:

- Describe the nature of electromagnetic radiation;
- Test the principles of electromagnetic shielding;
- Apply the principles of electromagnetic shielding to engineering design; and
- Identify constraints and tradeoffs of the Life History Transmitter.

MATERIALS

- Cell phones that get reception within the room*
- Heavy Duty Aluminum foil
- Large Ziploc® bags or other well-sealing bags (8" X 5" X 1")
- Sandwich size Ziploc® bags or other well-sealing bags
- Table salt
- Digital scale or kitchen measuring spoons
- 1000 mL Graduated Cylinder or 1 L plastic bottle.

* Alternatively the experiment can be done outside to maximize reception.

AUDIO/VISUAL MATERIALS

- Computer and projector for the PowerPoint
- PowerPoint http://www.sealtag.org/Resources.html

TEACHING TIME

- Two class period (100 minutes)

SEATING ARRANGMENT

- Whole-class instruction and small group activities

KEY WORDS

- Electromagnetic radiation, Faraday's cage, conductor, transmitter, constraints, tradeoffs, wavelength, frequency

BACKGROUND INFORMATION

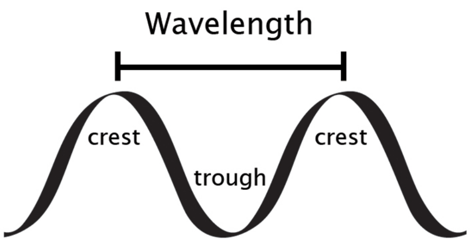
Process of Science

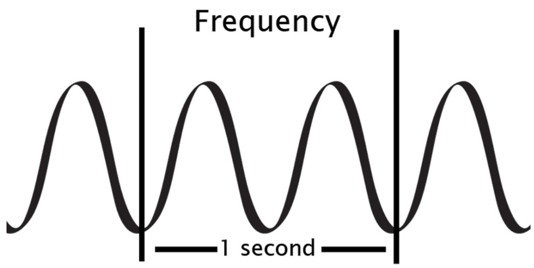
For students to begin the inquiry process, they must first understand the process of science. Science generally begins with an observation or information that leads to a question. For the LHX project this was the simple observation during an aerial survey that there were dramatically fewer Steller sea lions along the Aleutian Islands than in previous years. This observation led to a question: why are they not there and what is happening? The question develops into a hypothesis, a scientific explanation that is specific, testable, and logical. (It is important to remind students that a hypothesis is a declarative explanation.) For example, for the LHX project scientists developed the hypothesis that young Steller sea lions are dying in such large numbers that too few survive to an age where they can reproduce.

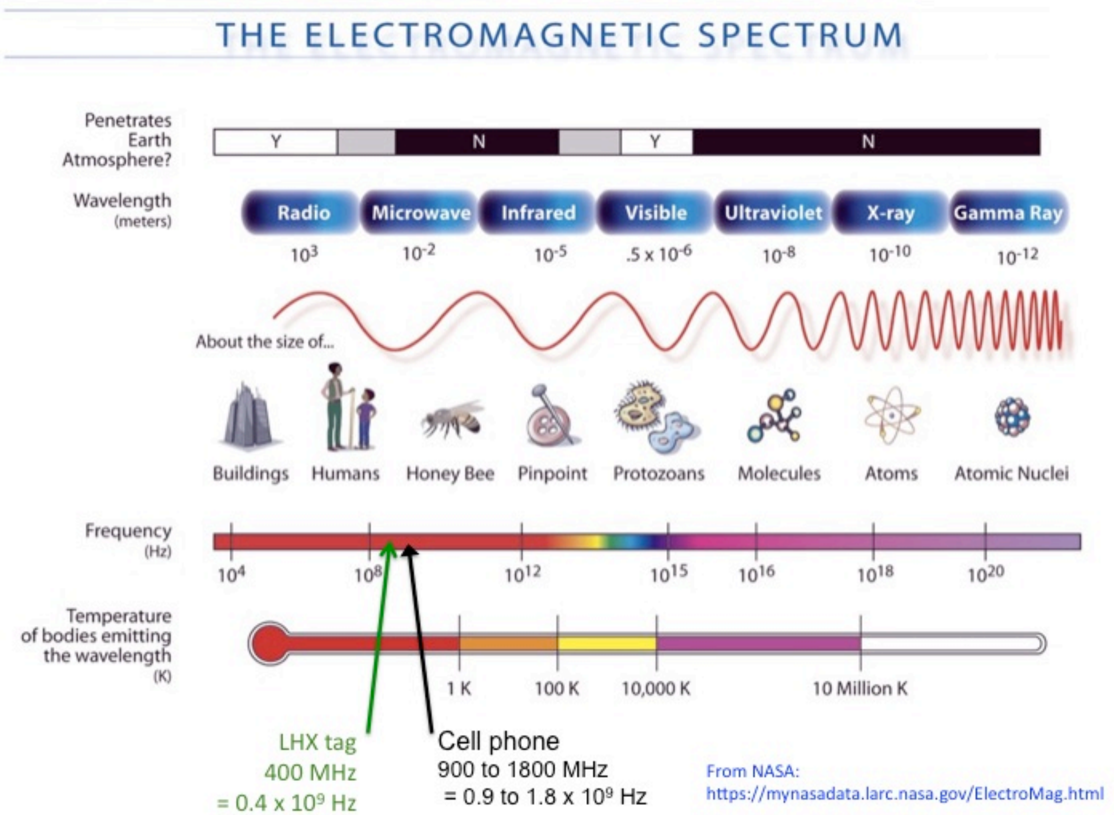
After developing a testable hypothesis, scientists typically study the scientific literature on the subject to see what if anything has been published. Next, they determine what data is specifically needed to test their hypothesis. Then they develop a method or use existing methods to collect data to support or refute their prediction. With this idea, they seek funding and any necessary permits. With these in place, they collect the necessary data, test their hypothesis and publish their results in scientific journals after their methods and analyses undergo peer review. Based on their initial findings or the reviews, scientists may revise their ideas and do more testing if necessary. Much of scientists' time is spent reviewing, revising, writing, and speaking about their results. Although we have presented this as a sequence of events, the science process is not often linear. See this science process flowchart: http://undsci.berkeley.edu/flowchart_noninteractive.php.

Nature of Electromagnetic Radiation and Shielding

Electromagnetic radiation is a form of energy that exhibits a wavelike quality as it travels. The waves have an electric field component and a magnetic component. The electric field component travels at a 90-degree angle to the magnetic field component. Each type of electromagnetic radiation varies according to its wavelength and frequency along the electromagnetic spectrum. The wavelength is the distance between two wave crests or troughs and the frequency is the number of waves that pass per unit of time. These two characteristics of waves change in opposite directions: the longer the wavelength, the shorter (lower) the frequency. The electromagnetic spectrum ranges from long wavelength (low frequency) radio waves to short wavelength (high frequency) gamma rays.







Cell phones use electromagnetic radiation in the form of electromagnetic waves to transmit and receive sound and data. A cell phone is basically a computer with a radio transmitter and receiver. It transmits and receives sound encoded in radio signals, but in the microwave range of frequencies. On a basic level, the cell phone sends radio signals to the cell tower and receives radio signals from nearby cell towers. There are many cell towers, usually 5 to 30 miles apart, that contain radio equipment and can send and receive radio signals to and from the cell phone. The Life History Transmitter works in a similar way. The LHX encodes digital information into the Ultra-High-Frequency (UHF) radio signal that it transmits to the ARGOS satellite system[1], which receives and decodes the transmissions. While cell phones only have to reach the closest cell tower that typically is no more than 30 miles away, the LHX tags have to reach satellites that at best are 375 miles away.

In general, all electromagnetic waves can be blocked or shielded. Short waves at the high frequency end of the spectrum such as x-rays and gamma rays are not easily blocked. They require lead or thick walls to shield them but do not travel as far. Longer wavelengths (lower frequencies) travel farther and are much easier to block than shorter wavelengths. A good analogy to help students remember the relationship between how far a wave travels and its frequency is to have students imagine a small ripple on a pond and a tsunami wave. A small ripple is a short wave and does not travel far. A tsunami wave is a long wave and travels thousands of kilometers. You can also use a jump rope to illustrate wavelength and frequency.

Short waves (high frequency) **-such as x-rays**	**Long waves (low frequency)** **such as cell phones and the LHX tag**
Do not travel as far	Travel further than short waves
Are not easily blocked	Easier to block than short waves

Cell phones use short waves with very high radio frequencies because the radio waves from cell phones do not have to travel far, and they are not easily blocked or shielded by many objects in the urban environment such as buildings. LHX tags use a lower frequency of about 400 MHz since the signal has to travel much farther. The downside or tradeoff is that the signal from LHX tags is shielded much more easily than the signal from a cell phone.

A Faraday's cage is a type of shielding made up of a conductor in which, when an electric field is applied, the charges rearrange themselves to cancel out the field inside. A conductor is a material that easily conducts an electric current. A microwave oven is a common example of a Faraday's cage that does not let any of the microwaves used to heat food outside. Faraday's cages are important for shielding equipment from lightning and other electromagnetic radiation. Other materials and molecules can act as a Faraday's cage. (For example, saltwater is a conductor, and the human body, as anyone who has been shocked by electricity can experience, is also a conductor. Provide this after experiment.)

See this Faraday cage simulation: http://en.wikipedia.org/wiki/File:Faraday_cage.gif.

When engineers design devices for use in a conductive environment like saltwater or inside the body of an animal, they have to find a way for their design to work in that medium or find an alternative solution. For the LHX, the solution is to store the information inside the archival satellite tag, and then have the tag transmit its data once it is outside of the body in air. Provide this information after the evaluation.

Overview of Learning Process

After learning generally how the LHX tag works, students will perform guided inquiry to determine if the LHX tag can transmit while inside the body of an animal and use the principles of electromagnetic shielding and Faraday's cage to determine why or why not. Students should write their hypothesis on an index card, and pair-share or in a small group, engage in a discussion of whether this is a good hypothesis or not, and should describe and write up how they would test their hypothesis. Students test their hypothesis using the materials provided (with guidance and suggestions) and write up and present their results.

Students should engage in group discussions about their evidence, how reliable their results are, what they would do differently, how they arrived at their conclusions, and the implications of their results.

LEARNING PROCEDURE

Go over the LHX project PowerPoint and introduce science-as-inquiry and electromagnetic radiation/shielding as whole class discussion. Have students create a working definition for a conductor. Discus what makes a good conductor and give examples (except saltwater or tissue). A good conductor is one that has many free electrons. Examples are copper wire, silver, gold, and aluminum.

Start by asking how cell phones work. Ask, when a phone call or text message is outgoing, what is happening in a scientific sense? How about incoming? After listening to student responses, ask students if cell phones give off any electromagnetic radiation? What type? Show the electromagnetic radiation figure and remind students that cell phones use radio signals or microwaves and where cell phones are in the spectrum. You can also demonstrate where the LHX tag is on the spectrum (400 MHz, = 0.4 GHz = 0.4 x 10^9 Hz).

How does the radio signal get to/from the phone? Students should know from the material that the cell phone has a battery and an antenna, just like an LHX tag. The battery powers the transmitter that sends and receives radio signals through the antenna back and forth to the cell tower. Instruct students to look at the number of bars on the cell phone. What does this indicate? The bars on the phone indicate the signal strength of the radio wave connection between the antenna and the cell tower. The signal strength will change as a result of the distance to the nearest cell tower and the amount of shielding by buildings, vegetation or obstacles. This is why often we get a better signal strength (= more bars) outside of a building than inside. If we drive towards a tower, we will get more bars, and if we drive away, we will get fewer bars. Students may remember instances where their signal strength as shown by the bars is weak, and they have had trouble communicating on their phones.

Part I. Teachers use a cell phone to help students determine if radio waves can propagate through tissue to understand how the LHX tag works. Ask students if radio waves can propagate or travel through tissue. Have students pair-share or as groups develop a hypothesis and write it on an index card. Ask students how they would test this and have them write it on the card. Ask students to defend their hypothesis based on the explanatory material. Assuming no one comes up with this idea, the teacher can let students know how to easily conduct the experiment. Depending on the number of cell phones, this can be done in partner pairs or with two students demonstrating at the front of the room.

An interesting way to see if radio waves travel through tissue is to put the cell phone in your lap and fold your body over it. Walk students through the process. What would students first want to check before conducting the experiment? Have students call each other first to demonstrate the phones are working and have sufficient signal strength or number of bars, then have one student call the other once they are folded over the phone. Typically, unless the classroom is in an area with exceptionally strong cell phone reception, the students should be able to call each other when both phones are not covered, but they should be unable to call a phone that is surrounded by tissue (i.e. covered in a lap). Sometimes, however, due to the size and shape of the person's lap and the cell phone reception, the experiment may not work since you need very close contact with the phone and surrounding tissue. Encourage students to brainstorm about how else they might test this. Students can try the experiment, again, at home by placing the cell phone between themselves and a friend or family member and hugging, while having someone else call their phone.

Part II. Building on the previous experiment, ask students to predict what will happen to the signal strength (number of bars) of a transmitter in air, in a Faraday's cage, and under saltwater to study the principles of electromagnetic radiation and shielding. Record their predictions on the whiteboard. Ask students how they would test this. Have students defend their hypothesis based on the explanatory material.

Students will learn that air does not block a signal, the Faraday's cage (aluminum foil) very strongly or even completely blocks the signal, and saltwater reduces the signal. Working in teams, students check their phones in air to make sure they have good signal strength within the room. This is also the baseline for their saltwater experiment. Note the number of bars.

Direct students to fashion an aluminum foil cover to completely surround the phone. Have them cut a small window into the aluminum foil right where the signal strength indicator bars are. Students should mark the foil where they need to cut and take the foil off the phone before cutting. Ask students how big should the foil cover be? Should the cover touch the phone or surround it? Students first test the phone in the air (see Figure 1) and then surrounded by the aluminum foil (Figure 2). They should be able to observe a drop in the number of bars, and ideally they should lose all reception. If reception is lost, then they will no longer be able to call that phone. Note that in areas with very strong cell phone reception complete loss of reception may not happen, though a drop in signal strength (fewer bars) should always occur.

Figure 1: 3 bars of signal strength

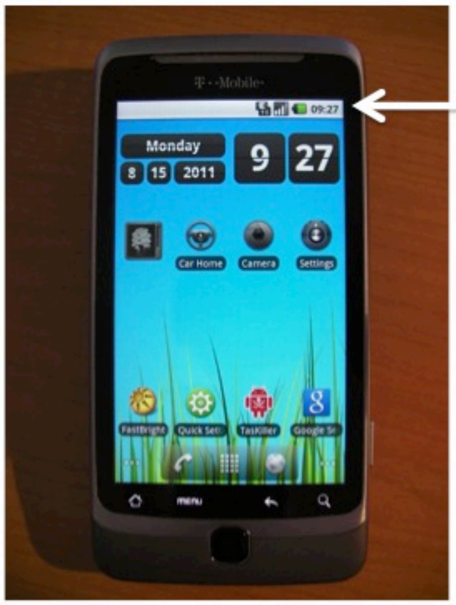


Figure 2: no signal

Have students prepare the saltwater. Explain that this is similar to ocean saltwater, but ocean saltwater has many other salts and ions. The average salinity of seawater is 35 parts per thousand. Ask students how many grams this would be in a liter. Students add 35 grams (about 6 teaspoons) of table salt to 1 liter (1000 mL) of water. Mix thoroughly. Carefully fill the zipper bags with saltwater, wipe them off, and *ensure that they do not leak.* You can double bag if in doubt! Have rags or paper towels on hand to check for leakage and immediately wipe up spills. Next, have students place the cell phones in dry zipper bags and close bags. This bag protects the phones from saltwater. To be safe you can double bag the phones as well.

Next, have students place one saltwater bag on table, and then the cell phone on top. Have them note signal strength (number of bars). Then lay a second saltwater zipper bag over the phone (which should be protected by its own bags) and note drop in signal strength. *Note*: signal strength may only drop a bit, especially in areas with strong cell phone reception. You may have to use a second water bag on top of phone. Different phones may work differently, since different companies use different frequencies. It may be best to try this yourself before class. It may also be difficult to read the signal strength bars through the water-filled zipper bags. Have each team record what occurred under the matching prediction on the whiteboard. Have students brainstorm as a class about why the saltwater does not completely shield the phone.

Part III. (Second class period) (Method contributed my Mary Koike) Teachers can use this evaluation to challenge kids to think about designing a transmitter that would work in a water medium. Give to each team of students a sheet of butcher paper. Begin by telling students, knowing what you know about cell phone transmission and reception, how would you design a transmitter that would work in a saltwater environment. Have them make a list of essential criteria that has to occur in order for transmission to take place. Let them discuss and write. Let them draw a picture. The picture will be a part of the evaluation process letting the teacher know if students understood that the transmitter:

- produces high frequency waves, a form of electromagnetic radiation
- sends that wave signal to a satellite
- has a battery and antenna that operates much like a cell phone battery and antenna
- cannot transmit through tissue (the body) or water since both are conductors that act like a Faraday's cage;
- has to be encased to protect it from saltwater and tissue growth;
- cannot be encased in a conductive metal container such as aluminum since it acts as a Faraday's cage.

In your design, how could you get the information? In other words, would the transmitter transmit in real time or would the transmitter store the information for later recovery? Have students discuss and write down their answer by their design with justification for their answer. Have each group share. Would the transmitter need to get to an air interface where it could transmit? How would you get the transmitter to the air/water interface? After each question, allow students to discuss, commit to paper, and justify.

Constraints are the imposed conditions, rules or regulations of the engineering designs. For example, the tag must be waterproof. Constraints will be covered in Lesson 5. Have students identify how well their design suits the purpose of the tag, a constraint.

Tradeoffs result when one of the design criteria can be met but at the expense of another. For example, more batteries mean the tag has more power and can work longer, but more batteries make the tag heavier. Are their any tradeoffs with their design?

Following this discussion, the teacher can explain again how the Life History Transmitter works and how engineering design met the challenges and constraints of working with animals in a saltwater medium. Are there any other challenges of working in saltwater, with animals? (Corrosion, tissue growth, pressure, battery life, size, etc.)

Give students a different colored marker than the first time and have them add to their drawings any information they would like to add on or change from the first time they went through the exercise.

Participation in class discussions provides opportunities for evaluation. The pre and post drawings serve as growth in understanding the LHX concepts.

EVALUATION

Participation in class discussions provides opportunities for evaluation. The pre and post drawings in Part III serve as growth in understanding the LHX concepts.

EXTENSION

Engineering Challenge:

- Students will use the principles of electromagnetic shielding to design a cell-free room.

Certain places need to be quiet and free from cell phone calls such as libraries, hospitals, and classrooms. Based on the student's new knowledge of shielding, ask how they would design a room so that cell phones do not work? What would you have to incorporate into your room? What are the criteria and what would the tradeoffs be?

CONNECTIONS TO OTHER SUBJECTS

Physics, Biology, Engineering

RESOURCES
Teachers Wiki for Cell Phone Use in the Classroom

http://melaniewiscount.wikispaces.com/Cell%20Phones%20in%20the%20Classroom

Anatomy of an Electromagnetic Wave:

http://missionscience.nasa.gov/ems/02_anatomy.html

The Physics of Cell Phones

http://www.yale.edu/ynhti/curriculum/units/2003/4/03.04.07.x.html

Saltwater Circuit: Saltwater is an excellent conductor!

http://www.hometrainingtools.com/saltwater-circuit-project/a/1344/

Engineering is Elementary: Science Engineering and Technology

http://www.mos.org/eie/science_engineering.php

Science Buddies: Free Science Fair Project Ideas, Answers, and Tools for Serious Students

http://www.sciencebuddies.org/science-fair-projects/project_engineering.shtml

Teach Engineering: Resources for K-12 (other great links at bottom of page)

http://www.teachengineering.org/engrdesignprocess.php

What is the 12-step design process?

http://wiki.answers.com/Q/What_is_the_12_step_design_process

NATIONAL SCIENCE EDUCATION STANDARDS

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Structure and properties of matter
- Interactions of energy and matter
- Forces and motion

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

OCEAN LITERACY: ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS

Principle 5. The Earth supports a great diversity of life and ecosystems.
Principle 7. The ocean is largely unexplored.

Lesson 5: Animal Crime Scene Investigations: Heat Transfer, Mass and Surface-to-Volume Ratios

ENGINEERING DESIGN CHALLENGE:

The change in the body temperature measured by the LHX tag informs scientists how the Steller sea lion may have died.

FOCUS

Heat transfer: conduction, convection, and thermal radiation, cooling curves, changes in heat transfer with: mass and surface-to-volume ratios

GRADE LEVEL: 9 - 12

FOCUS QUESTIONS

- How does the LHX tag use temperature to determine time and cause of death?
- Which cools faster at the same ambient temperature, a large body or a small body?
- Which cools faster at the same ambient temperatures, a body in air or in water? Why?
- Does the shape of the body matter? (Do surface-to-volume ratios affect cooling?)

LEARNING OBJECTIVES

Students will:

- learn about the principles of thermal conduction and convection;
- learn how surface-to-volume ratios change with shapes of objects and how this influences heat dissipation;
- determine the cause of death and mass using sample cooling graphs for a Steller sea lion body; and
- understand how scientists design experiments to answer specific questions.

MATERIALS

- Body cooling graphs
- PowerPoint http://www.sealtag.org/Resources.html
- Modeling clay
- Thermometers, digital or alcohol
- Cooler or bucket with water
- Ice
- Excel lookup table
- Digital scale
- Watch or stopwatch

AUDIO VISUAL MATERIALS

- Computer and projector for the PowerPoint

TEACHING TIME

- Two class periods (100 minutes)

SEATING ARRANGEMENT

- Whole class and small group activities

KEY WORDS

- Heat, temperature, thermal equilibrium, Newton's Law of Cooling, cooling rate, kinetic energy, convection, conduction, thermal radiation, surface-to-volume ratio, specific heat capacity

BACKGROUND

Temperature

Temperature is the measurement of how hot or cold an object is. Temperature measurements using a thermometer are indirect. For an alcohol or mercury thermometer, they are based on how liquids expand when they are heated relative to a given scale. Digital thermometers typically use electronic sensors whose electrical properties such as resistance change with temperature. Heat is a measure of internal energy transferred from one object to another. Heat travels from a higher temperature substance to a lower temperature substance until both have the same temperature (thermal equilibrium). According to Newton's Law of Cooling, the rate of change of the temperature of an object is proportional to the difference between its own temperature and the ambient or outside temperature. In simple terms, this means that a larger temperature difference between and object and its surroundings will result in a higher rate of temperature change. To use a sea lion example, for two dead, sea lion bodies of the same size and same internal temperature in water of two different temperatures, the one in the lower temperature water will cool at a faster rate. In addition the relationship between the temperature of the object and the ambient temperature, the mass of an object also influences how much it will cool. Larger masses cool more slowly than smaller masses. All other things being equal, a larger mass contains more energy and thus takes longer to transfer its energy in the form of heat to a lower temperature substance. In this lesson, students examine the cooling rates of different masses of clay in ice water of the same temperature over time. Here, **cooling rate** can be defined as the **amount of heat lost per unit time, using temperature as an approximation for heat.** Because the cooling rate is affected by an object's mass, the LHX uses this difference in cooling rates to determine the cause of death and the mass of the animal at the time of death.

The temperature of an object relates to the amount of kinetic energy (energy of motion) its particles have. As an object is heated, the particles move faster. At the level of atoms, the energy of heating causes the atoms to absorb energy and their electrons move to a higher, excited state. Heat is transferred from one object to another in three ways: conduction, convection, and thermal radiation. Conduction happens when two substances touch each other in close proximity so that the kinetic energy transfers from one to the other. Imagine an electric stove with a pot on top. The kinetic energy passes through a small stationary boundary between the two objects. Convection occurs when a gas or liquid surrounding an object or substance transfers heat along with the movement of the fluid. A chicken on rotisserie is an example of air convection. Another type of convection is Brownian motion of particles in a fluid, which is often observed while looking at bacteria under a microscope. Thermal radiation is the transfer of heat energy by electromagnetic radiation as when the sun warms the earth.

Students will discover that smaller masses cool more quickly, and as surface-to-volume ratios increase, objects cool more rapidly since there is more surface area in contact with the water. The surface-to-volume ratio is the surface area per unit volume of an object. Objects in water cool much more quickly than in air due to its higher specific heat capacity. Specific heat is the "measurable physical quantity that characterizes the amount of heat required to change a substance's temperature by a given amount."[1]

LEARNING PROCEDURE

Have students visit the project website prior to class (www.sealtag.org). Introduce the Life History Transmitter Project with the PowerPoint supplied.

Part I: **What causes different cooling rates?**
Students will:

- Design and conduct an experiment investigating what causes different cooling rates.
- Use the scientific method to design experiments and reach conclusions
- Describe their results orally and on paper

Discuss the scientific process and present how scientists do inquiry. Have students discuss what might affect how quickly warm objects cool in a colder environment. Have them describe what is happening in terms of energy transfer and at the molecular and atomic level. Explain mass, volume and surface to volume ratios, thermal conductivity and convection and radiation. Explain that the larger the mass the larger the amount of energy that is transferred in the cooling process. You can demonstrate this with two unequal chunks of ice. The larger chunk takes longer to melt. Explain that as objects grow larger the surface to volume ratio becomes smaller. This can be illustrated by comparing the formula for surface area of a sphere:

Surface area = 4 pi r^2 to the formula for the volume of a sphere:
Volume = 4/3 pi r^3.

Thus, surface area increases with the square of the radius, while the volume increases with the cube of radius.

Have students work in teams. Ask students to develop a hypothesis about which masses for a given shapes will cool faster: smaller or larger masses? Use a sphere as an example. (Answer: smaller masses will cool faster). Ask students to hypothesize what shape will cool faster for a given mass, a sphere or a cube? (Answer: a cube will cool faster since it has more surface area per unit volume than a sphere). Students will model different shapes and sizes for the following experiments. Ask the students why we would not want to test different shapes and weights at the same time? (Talk about variables and testing a single variable at one time.)

We suggest using spheres (balls) and cubes or bricks as experimental shapes. This is because they are easy to form, and both surface area and volumes can be easily calculated from simply diameter and length measurements. Students must weigh each shape, and it is recommended that students weigh out a mass of clay and then form this into specific shapes. Students can test their shapes and see if their predictions match their hypothesis and discover the relationships between shape, volume, surface-to-volume and thermal conductivity and convection.

As students design their experiments and get results here are some questions they should answer:

- How did they (the scientist) design their experiment?
- What was measured (variables)?
- What was your result (describe the graph)?
- What was your conclusion (based on each graph)?
- What is your evidence?
- What are potential sources of error with these measurements?
- How sure are you about your conclusion?
- What would you need to be more certain about your results?

In student teams, have the students write up how they plan to do the experiment. Direct students to decide on the weight and shapes of their modeling clay to test their hypothesis. We suggest using masses between 50 grams and 200 grams (350 grams max.) to be able to complete cooling measurements within one period.
Have students graph and present their results.

Experimental Procedure:

1. Each student team gets a bucket large enough to accommodate 3 or more masses.
2. Instruct students to fill each bucket with ice and water. Allow time for ice to chill water. Mixture should be water mixed with ice. As long as there is some ice floating in the water, the temperature of the water should be zero degrees Celsius.
3. Have each student in the team make a different clay mass from one of two different shapes (a sphere/ball, or a brick) out of modeling clay to test. For varying mass suggest they use 50, 100, 150 and 200 grams. Students can subsequently compare different masses of the same shape, and can also compare different shapes of the same mass.
4. For the brick shape, use a mass off 200g only (About 2.5 cm x 4.5 cm x 11.5 cm, see Figure 6.)
5. Measure the temperature of the water. It should be near zero degrees Celsius.
6. Insert a thermometer into each clay model. Have students pay particular attention to placing the sensitive part of the thermometer as close to the core of the clay mass as possible. See Figures 1 and 2 below.
7. Allow shapes to equilibrate at room temperature for 5 minutes.
8. Measure and record the temperature of the clay model.
9. Place the clay model into the ice-water mixture and start the timer/stopwatch or note time (See Figure 1 below).
10. Measure and record the temperature every 30 seconds for 15 minutes. Students should find a way to work as a team and check each of their models at the appropriate time.

11. One student per team records the results. Students graph their results, and present their information to their peers. See Figure 5 for sample results from our own testing.
12. As a class students develop conclusions about the relationship between mass and cooling rates.
13. As a class students develop conclusions about the relationship between mass and shape (surface-to-volume ratios).

Dr. Horning's Tips for getting good results in cooling experiments:

1. If possible, use digital thermometers. Alcohol thermometers will work, but not as well. Plus, they may break resulting in sharp glass shards. Do not use a mercury thermometer because of the safety hazard!
2. You need one thermometer for each clay shape and measurement series. DO NOT pull the thermometer out during one series in order to stick it into another shape and make another measurement. Pulling a thermometer out during a series will result in cold water getting into the core and your results will be way off!
3. Measure out the weight of clay, and work it a bit and roll it into a ball.
4. Cut this ball in half.
5. Place the sensitive part of the thermometer at the core of one half of the ball. See Figures 1 and 2 below. For a digital thermometer, the sensitive part is the little nub at the end of the sensor cord. For an alcohol thermometer, the sensitive part is the little reservoir bulb at the bottom of the thermometer by the low end of the temperature scale.
6. If using a digital thermometer, coil the sensor cable a bit before leading it out of the clay, see Figure 1. This is because the cable also conducts heat away from the core. A short length of cable from core to outside may result in quicker cooling.
7. Press the two halves of the clay ball together. Work them a bit and smooth out the joining edges. Make sure the clay halves are well joined and there is no air between them. This way you have less cold water trickling in to the core, which may change your results.
8. Where the sensor wire or thermometer glass enter the clay ball, pay particular attention to making sure there are no gaps.
9. If you are using an alcohol thermometer, immerse just the clay shape in the ice bath, but try to keep the external glass body of the thermometer out of the water. For a digital thermometer, immerse the clay ball but as little of the sensor cable as possible (see Figure 4).
10. Do not move the clay shape once it is in the water, and do not agitate the water (unless students are studying convection by water flowing over an object).

Part II: Interpreting cooling curves to determine cause of death
Students will:

- interpret graphs to determine a Steller sea lion's cause of death.
- describe how scientists use data to test their hypotheses.

Use the PowerPoint to explain how to read the graphs on the cooling curves. Using the sample body cooling graphs from the website, have students determine the cause of death for the animal with their particular graph; do this for three different scenarios using the three different cooling graphs:

1. Gradual cooling indicates non-injury death for example by starvation or from disease.
2. Abrupt cooling indicates death by predation with immediate tag release
3. Gradual cooling at a rate much quicker than expected for a given body mass also indicates predation with partial dismemberment.

Have the students write and/or describe how they determined the cause of death.

Discuss: Have students discuss their conclusions with the class and provide logical explanations for their evidence. Have students discuss potential sources of error with this method.

Part III: (Higher grades) Teacher presents the Steller sea lion "crime scene" scenario. The educator can demonstrate what happens in the case of a traumatic death by breaking apart one of the warmed clay models with a thermometer inside and placing the thermometer directly into the ice water. What happens to the temperature? Explain that students are finding out the time of death in the case of a non-traumatic death where the body remains intact and gradual cooling occurs.

Experimental Procedure:

1. Set up buckets of ice water for each group of students and ensure the water is at 0^0C.

2. Immediately prior to the experiment, the instructor takes clay spheres from Part III of any of the masses listed in Figure 5 and checks to make sure they are at room temperature (25^0C). Alternatively, the clay figures can be warmed to 25^0C in an incubator prior to the experiment.

3. Once the spheres are at 25^0C, the instructor drops them into students' buckets of ice water and records the time. (Keep this time secret until after the calculations.)

4. A few (2-7) minutes later, students carefully insert their thermometer into the sphere in the buckets of ice water, noting the time and measuring the temperature every 60 seconds with the thermometer, for at least 5 minutes (no more than 10).

5. Students record their data and plot it on a graph of temperature as a function of time.

6. At the end of the temperature measurements, the students weigh their clay sphere. (If no scale is available they can be told the mass of their sphere "animal").

7. Students are told that their 'clay animals' normally have a body temperature of 25^0C. Students have to determine when the clay figure 'died' (was dropped into the ice water).

8. To do this, they should try to match their own graph with the corresponding curve in Figure 5, based on the body mass of their clay figure. Students should identify where along the matching curve in Figure 5 they took their first temperature measurement. They should see how many minutes after time 0:00 this measurement must have been taken (for example their first value was 13^0C at 14:15

or 2:15 p.m. for a mass of 100g, which matches the elapsed time of 5 minutes for the yellow curve in Figure 5).

9. They then need to subtract this elapsed time (5 minutes in the example) from the time of their first measurement (14:15) to determine the time the clay figure was first dropped into ice water (14:10 in the example).

10. Students present their results.

CONNECTIONS TO OTHER SUBJECTS

Physics, Mathematics, Biology, English/Language Arts

EVALUATION

The presentation of results and a lab report of the experiment as well as class participation in discussions provide opportunities for evaluation.

FIGURES

Figure 1: The sensor of the digital thermometer is placed at the center core of the clay sphere of 100g, which is cut in half. The cable is wound around the sensor, reducing the direct cooling effect of cold water onto the sensor via the sensor cable. The two halves are then joined.

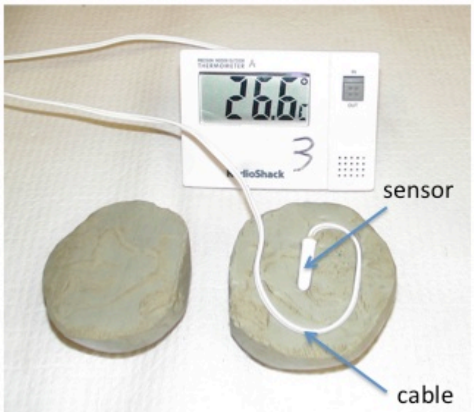


Figure 2: Two smaller 50 gram masses. The left shows the digital thermometer sensor placed at the core, the right one shows an alcohol thermometer placed so that the sensitive bulb is at the core of the clay ball. The halves are then joined.

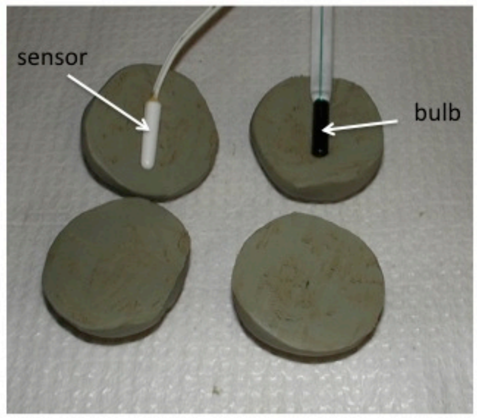


Figure 3: a 200 gram mass shaped into a brick of 2.5 x 4.5 x 11.5 cm and cut into two halves for placement of thermometer. An alcohol thermometer is placed so that the sensitive bulb is at the core of the brick. The brick halves are then joined.

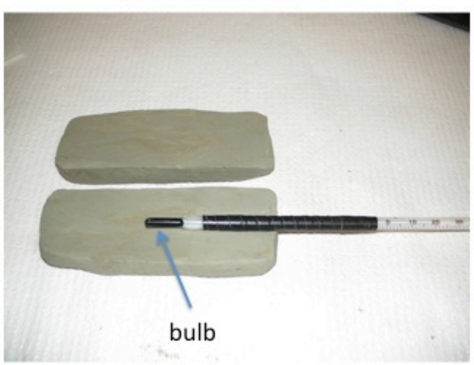
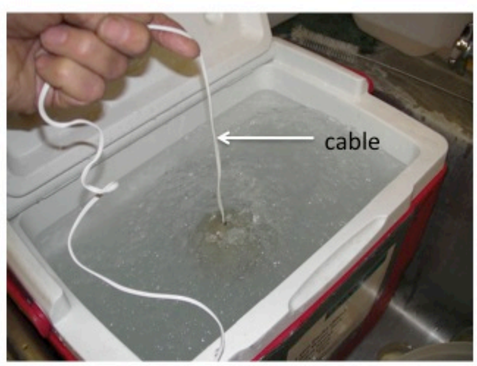


Figure 4: a 200 gram spherical clay model is placed in the ice water in a cooler. The mass can be held (suspended) by the sensor cable (shown here) or by the glass body of the thermometer (not shown here). For a still water simulation, the mass is not moved. To simulate moving water, the mass can be pulled up and moved down constantly.



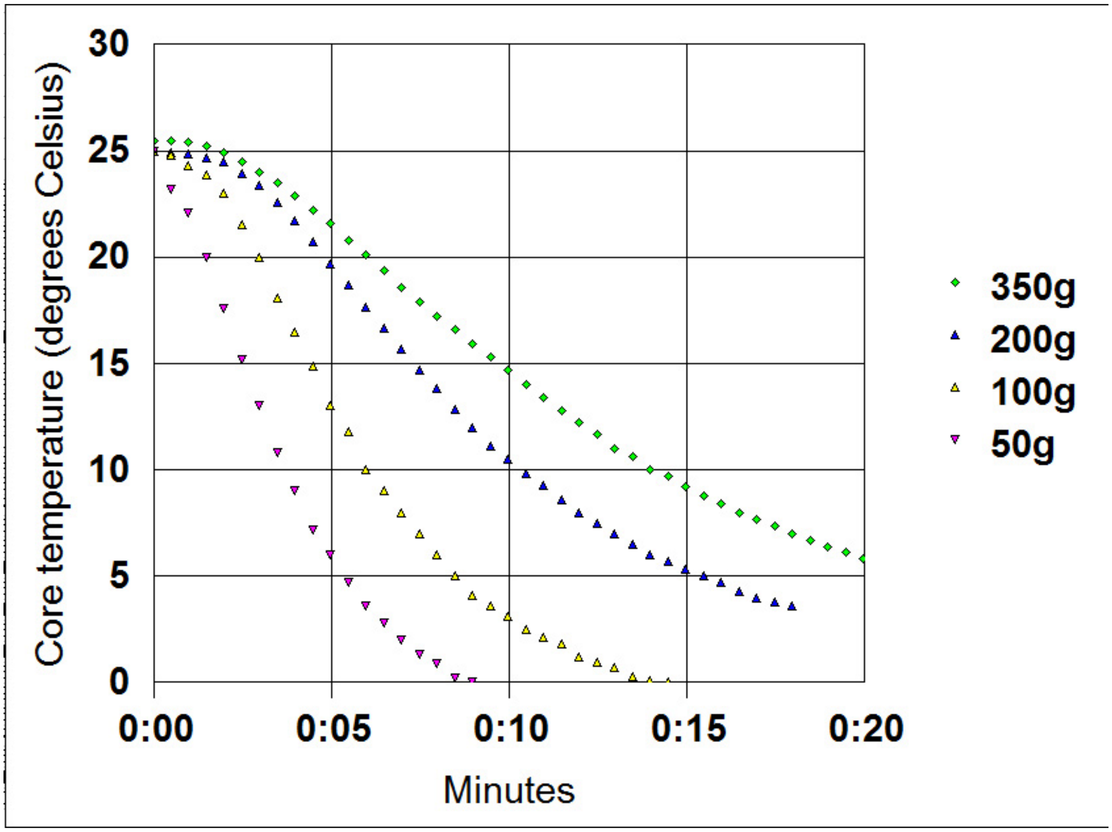


Figure 5 (above): Smaller masses cool quicker! This graph shows the cooling rates for four different spherical clay masses of 50, 100, 200 and 350 grams, in ice water of zero degrees. Core temperatures were approximately 25 degrees Celsius at the beginning of the experiment.

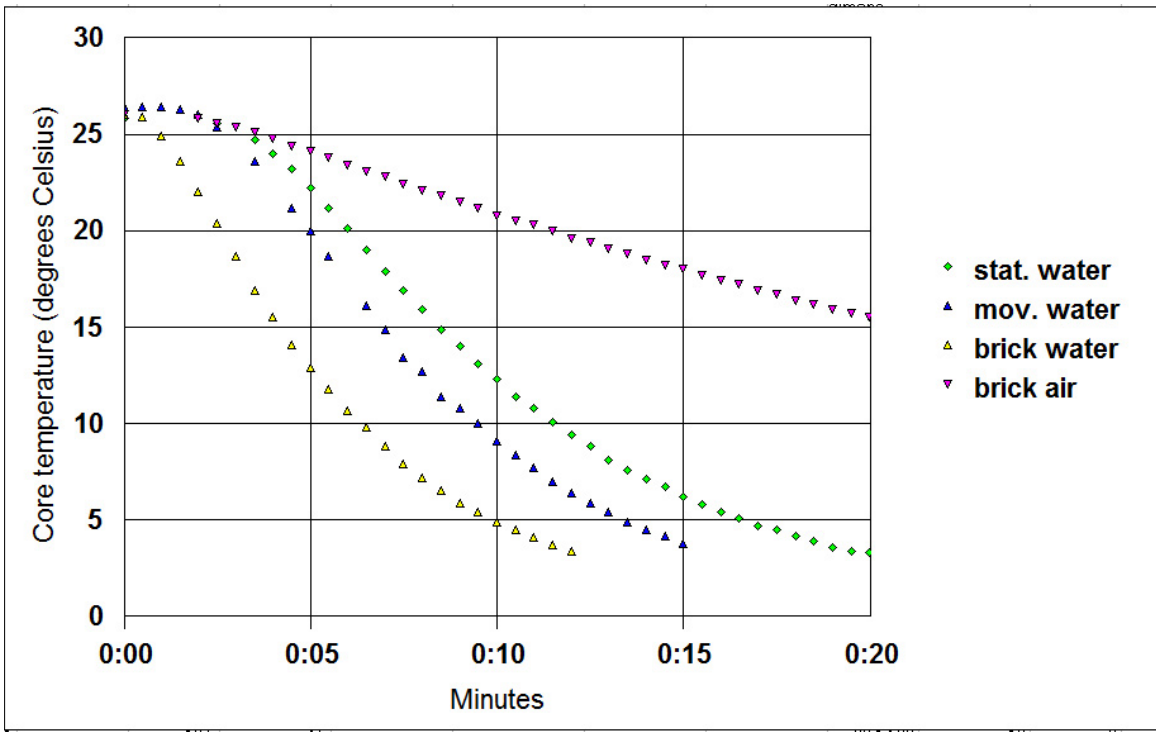


Figure 6 (above): Shape, type and speed of medium matter! This graph shows the cooling rates for four clay masses of 200 grams. The four masses differ by shape and by the cooling medium. The initial core temperatures were about 26 degrees for all four masses.

2.1. BASELINE: The green diamonds show a spherical mass cooling in stationary (non-moving) ice water of about zero degrees. This curve also corresponds to the blue curve in Figure 1.
2.2. FLOW SPEED: The blue triangles show the same spherical 200g mass cooling in moving (flowing) water: the mass cools quicker!
2.3. SHAPE: The yellow triangles show the cooling of a 200g mass in the shape of a flat brick, cooling in stationary water. The brick has dimensions of 2.5 cm thickness, 4.5 cm width and 11.5 cm length. The brick (yellow triangles) cools much quicker than a sphere (green diamonds) under identical conditions.
2.4. MEDIUM: The purple inverted triangles show the cooling of a 200g brick (same dimensions as above) cooling in air of about 0 degree Celsius (inside a refrigerator). Cooling in air (purple) is much slower than cooling in still water (yellow).

EXTENSION

Compare air-cooling versus water-cooling. Air-cooling should be done in a refrigerator using a digital thermometer with cable sensor so the readout unit can be kept outside and the refrigerator door closed.

RESOURCES

[1]*Heat Capacity*
http://en.wikipedia.org/wiki/Heat_capacity

Temperature
http://en.wikipedia.org/wiki/Temperature

Inquiry-Based Learning
http://www.neiu.edu/~middle/Modules/science%20mods/amazon%20components/AmazonComponents2.html#components

Teaching Physical Concepts in Oceanography
http://www.tos.org/hands-on/teaching_phys_concepts.pdf

NATIONAL SCIENCE EDUCATION STANDARDS

Content Standard A: Science as Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science
- Structure of atoms
- Structure and properties of
- Forces and motion

Content Standard E: Science and Technology
- Abilities of technological design
- Understandings about science and technology

Content Standard G: History and Nature of Science
- Science as a human endeavor
- Nature of scientific knowledge

OCEAN LITERACY: ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS

Principle 5: The earth supports a great diversity of life and ecosystems.
Principle 7: The ocean is largely unexplored.

Lesson 6: Engineering Tradeoffs: Buoyancy versus Battery

ENGINEERING DESIGN CHALLENGES:

-The antenna of the LHX tag must float above the water in order for its signal to reach a satellite.
-The battery must be as large as possible to provide sufficient power to transmit as much data as possible.

FOCUS: Buoyancy, engineering, design constraints, tradeoffs, Archimedes Principle

GRADE LEVEL: 9 -12

FOCUS QUESTIONS

- How do engineers balance criteria, constraints and tradeoffs?

LEARNING OBJECTIVES
Students will:
- Examine engineering constraints and tradeoffs as they apply to the LHX.
- Apply Archimedes principle to calculations for the "tag" design.
- Design their own prototype" tag" that meets criteria and constraints.
- Describe how new technologies enable new lines of scientific inquiry.
- Communicate their recommendations and solutions.

MATERIALS
Per student or group:
- PVC pipe, ¾ inch, two types, cut to 12 cm lengths
  (One type is called "Type 2", wall thickness 1.5mm, the other type is called "Schedule 40", wall thickness about 3.5 mm.)
  Both are available in most hardware stores for pennies per foot.
- OR 20 oz soda bottles with lids that close*
- Pennies, 12
- 500 mL Beaker or large, 32 oz. yogurt cup
- Small metric rulers (10 cm)
- Graduated cylinder (1000 mL) if using soda bottles instead of PVC tubing

*Soda bottle's shape will make it difficult to calculate an exact volume.

For class:
- Clear packing tape
- Digital scale

AUDIO VISUAL MATERIALS*
- Computer and projector for the PowerPoint
- PowerPoint http://www.sealtag.org/Resources.html
- LHX CAD Drawing:
  http://www.sealtag.org/images/AM-M229A.1x1-3C%201xPC.LHX.PDF

*Alternatively, materials can be provided as handouts

TEACHING TIME

- Two class periods (100 minutes)

SEATING ARRANGEMENT

- Whole class and small group instruction

KEY WORDS

- Buoyancy, Archimedes Principle, density, engineering, design constraints, tradeoffs, optimization, prototype

BACKGROUND

Buoyancy

When you float in pool or bathtub and notice that you feel much lighter, this is buoyancy. Buoyancy "is a force exerted by a fluid, that opposes an object's weight." [1] This is the force that causes ships to float. On an object in water such as a boat, there are two forces acting on it: the force of gravity and the pressure of the water column below the boat. Since pressure increases with water depth, the pressure below the boat is actually greater than the pressure at the surface. * This pressure difference is the buoyancy and is equal to the amount of water the boat displaces. The Archimedes Principle describes this phenomena as, "Any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object." The weight of the displaced fluid can be calculated by the equation W = m x gravity, where mass (m) is equal to its density (p) times its volume (V), m = pV. Students may find it confusing that buoyancy does not depend on the weight or shape of the immersed object, only the weight of the displaced fluid. Whether an object will sink or float depends on its density. If it is denser than the surrounding fluid, it sinks. If it is less dense, it floats.

In designing objects for use in water, buoyancy is an important factor to consider. Marine engineers consider buoyancy when designing vessels and oil rigs, and engineers designing products for use in the marine environment also consider buoyancy. The Life History Transmitter takes advantage of the principle of buoyancy to free itself from the body and float to the water's surface. Inside the tag, the antenna must float above the surface a certain distance in order transmit its information to a satellite.

> *(You can demonstrate increasing pressure with depth using a large plastic bag and a bucket. Have students put their arm inside the plastic bag, and then put their arm in the bucket without allowing water into the bag.)

Engineering

Engineers often have to deal with design constraints and tradeoffs. A constraint is a restriction on the degree of freedom you have in providing a solution. One of the main tag constraints is size. In order not to cause problems for the animals, LHX tags cannot be larger than 1% the size of the animal it will go inside. A tradeoff is a balancing of factors that cannot all be achieved at once. In the case of the Life History Transmitter, researchers need a battery that will last the lifetime of the animal, at least ten years. After ten years. The battery still has to have enough to power to be able to successfully send large amounts of data (up to ten years worth) to a satellite. However, batteries are heavy and take up a lot of space. Additionally, the tag must float a certain distance above the surface in order for its transmissions to reach a satellite. There is a tradeoff between the life of the battery and the tag's ability to float. The larger and heavier the battery, the longer it's life and the more transmissions a tag can make. However, the heavier the battery, the lower the tag floats in the water, which also reduces the percentage of transmissions generated by the tag that will reach a satellite. In addition, tags have to be strong enough to sustain immense pressures when their host animal dives to depths of 500 meters or more. To make tags strong enough, they need to be built out of stronger or thicker material, but that often adds weight. Therefore, a stronger tag for a deeper diving animal may float less unless it holds smaller or fewer batteries. Each aspect of the tradeoff creates a reduction in the function of the tag. The best design is one that meets all criteria and addresses all constraints while minimizing tradeoffs. Engineers call this "optimization".

The key difference between science and engineering is that engineers calculate the parameters of the design and test their idea whereas scientists design an experiment to test their hypothesis. When engineers test their products to see if their calculations are correct, this is called validation of concept. Engineers validate their concept by creating a prototype or model for testing.

LEARNING PROCEDURE

Have students visit the project website prior to class. Introduce the Life History Transmitter Project with the PowerPoint supplied. Describe the process of engineering using the resource websites listed below.

Have students describe constraints and tradeoffs in engineering. Based on what students now know about the LHX tag and the biology and environment of Steller sea lions:

- How would they build their own LHX tag (i.e. what shape, size)?
- What materials would they use?
- What problem(s) are they addressing?
- What would be their primary design criteria?

Part I. Show them the PDF CAD image of the LHX tag and show them the design specifications below. Tell students they will be building their own model tag using the materials provided. The PVC pipe represents the housing (outer shell) of the tag. Start with the thinner of the two PVC tube types (the one that is called "Type 2" and has a wall thickness of about 1.5 mm). Have students tape one end of the tubes closed with the clear packing tape. The pennies represent the batteries. The students are design engineers and the scientist (educator) is the client. Have students calculate and test how big of a "battery" you can fit and still meet the design specifications. Have students test their design using the materials available to see if their calculations are correct.

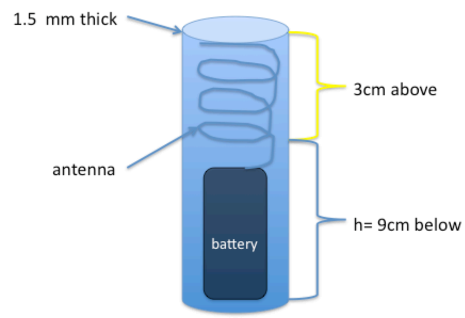
First, have students create a drawing of their tag (like the one below), illustrating the design specifications of the tag prototype.

The design criteria or specifications are:

- Antenna (imagined) inside the pipe must float 3 cm above the water.

- The “tag” must float without toppling over.
- The tag must have the largest possible battery for a given depth rating.

Example:



Have students recall the definition for buoyancy, a force exerted by a fluid that opposes an object's weight. They can figure out that the buoyancy of an object is equal to the weight or mass of the volume of water displaced. We want 3 cm of antenna to float above the water’s surface. Since the size of the pipe is 12 cm, 9 cm is below the water. This is the amount of water we want to be displaced (equal to its buoyancy) so that the top of the tag floats 3 cm above the water.

12 cm -3 cm = 9 cm below the water is displaced

Ask students how they would figure out the weight of the displaced water.

One possibility is to fill the cylinder up to the 9cm mark and weigh the water. However, this is inaccurate since it does not include the volume of the PVC tube. Therefore, as engineers we calculate the weight of displaced water.

Use the calculation for mass, m = pV. First, we need to calculate the volume of the water displaced by the cylinder. Have students recall the equation for calculating the volume of a cylinder: Volume (V) = Πr^2 x height (h)

Now we need to fill in the equation:

V= (3.14) x 1.335 cm^2 (the radius for our ¾” PVC pipe is 1.335 cm) x (9cm) = 50.39cm^3

To determine the weight or mass of water, water has a density (p) of 1 g/ml (or cm^3).

50.39 cm^3 x 1g/cm^3 = 50.39g

Thus, the weight of the displaced water is 50.39g. We know that PVC alone is a fairly light plastic, yet it is heavier than water and will sink. The PVC model LHX tag will need the air volume inside of the PVC tubing to float. How much weight left do we have for the batteries? Have students brainstorm about how would you calculate this.

Optional Activity: As good engineers, students can also calculate the weight of the tube from these dimensions:

Outer diameter: 26.7 mm, Inner diameter: 23.6 mm (for Type 2, which has a wall thickness of 1.55 mm). The density of PVC can be looked up in reference books, it is 0.0506 lb/in^3 = 1.4 grams/cm^3. The amount of PVC in 12 cm of type 2 tubing is calculated as the difference in volume between the inner and outer cylinders:

V_{out} = 3.14 x 1.335 cm^2 x 12 cm = 67.188
V_{inn} = 3.14 x 1.18 cm^2 x 12 cm = 52.492
The volume of PVC in the tube is $V_{out} - V_{in}$ = 14.696 cm^3

At the density of 1.4 g/cm3 this amount of PVC should weigh 20.57 grams.
However, this does not include the weight of the tape used to close the bottom, so the weight of 22.1 is better to use (more accurate).

Weigh the 12cm long section of the thinner-walled Type 2 tube with the tape = 22.1 g. To get the number of batteries, you subtract the weight of the cylinder (22.1g) from the water displaced (50.39g) to get the maximum weight of batteries you can add to have 3cm floating above the surface: 50.39g – 22.1g = 28.29g of battery weight

This is the total battery weight. Next you need to weigh the individual "batteries" to see how much they weigh per battery. Rather than weighing a single penny, since the weight may vary, have students weigh all 12 and get the average weight of a single battery. Then students can calculate how many batteries will get them close to 28.29 g of weight:

28.29/2.5 g per battery = 11.3 pennies.

However, you cannot have the tag height below 3 cm and there are no partial pennies. The answer is 11 pennies. Have students test their calculations on the prototype with their materials.

Part II. Optimization (**Higher grade levels**) Students calculated and tested their LHX transmitter prototype based on the criteria provided. However, the real world scenario is a little bit more complex: LHX transmitters have their best performance when the antenna floats about 3 cm above the water. However, even when less of the antenna shows, the tags can still transmit, though not all transmissions will reach a satellite. The lower the transmitters float in the water, the fewer transmissions will reach a satellite. If this is the case, good engineers will start to look at whether the 11-penny battery in Part I is the best way to go. It is possible that a transmitter with more than an 11-penny battery may work better, if the 'penalty' of less floatation is offset by the gain in battery size/power.

Provide students with the following case scenario: To test the idea above, engineers first conducted a battery test to see how many transmissions a "one penny" battery can power. In our 'penny LHX tag model' the tests revealed that a one-penny can provide enough power for 100 transmissions: 1 penny = 100 transmissions.

Next, engineers conducted a test to see what the reduction in performance was when a tag floats with less than 3 cm of antenna showing. This is what the tests revealed:

a) Exposure of more than 3.5 cm yields no change (100% of transmissions will reach a satellite).
b) Below 3.5 cm of exposure there is a penalty of 15% for each cm lost. For example, at 3.5 cm of exposure 100% of transmission reach the satellite, at 2.5 cm of exposure, satellites receive only 85% of transmissions, and at 1.5 cm of exposure satellites receive only 70% of transmissions.
c) Below 1cm of exposure, no transmissions will reach any satellite.

Armed with this new data, the student engineers can now calculate the optimal battery size for an LHX tag, using the attached LHX Tag Battery Size Design Worksheet (p. 55) and LHX Battery Optimization Table (p. 56). In multiple steps, the students can calculate the weight for a given number of pennies (i.e. from 8 pennies all the way up to 20 pennies) and as a result the amount of floatation (the number of antenna cm exposed). From the number of pennies they can calculate how many transmissions an LHX tag can make (# pennies *100). From the floatation they can calculate if any "penalty" exists (if floatation is less than 3.5 cm) or if the tag will not transmit (less than 1cm of exposure). They will determine that the optimal battery size is 13 pennies. Though a tag with 13 pennies only has an exposure of 2.25 cm and incurs a total penalty of 18.78% of transmissions not reaching a satellite, it will yield 1,055 transmissions, as opposed to an 11-penny battery tag with 3.14 cm of exposure, a 5.38% penalty and 1,040 successful satellite transmissions. This calculation illustrates how engineers optimize performance.

CONNECTIONS TO OTHER SUBJECTS

Mathematics, Physics, Engineering

EVALUATION

The presentation of results and a report of the prototype testing as well as class participation in discussions provide opportunities for evaluation.

EXTENSION

Explain that the tag has another tradeoff that affects buoyancy, the thickness of the PVC pipe or tag wall. The thicker the tag wall, the more pressure the device can withstand. Ideally, a thicker-walled pipe would be better because it could withstand more pressure, but the thickness of the pipe affects its buoyancy, stability, and the amount of batteries the tag will hold.

How did engineers decide how thick the tag walls should be? Ideally they would do calculations and pressure-test the tag prototype. Have students repeat the same process they used to calculate and test their "tag" with a thicker-walled pipe to see how the wall-thickness affects buoyancy, batteries, and stability. Use the 'Schedule 40' PVC tubing. Twelve centimeters of this tubing weighs considerably more at 38.3 grams, leaving less margin of weight for batteries to get the desired floatation. Students will find that they cannot obtain 3cm or more of floatation with this heavier material. Five pennies would theoretically yield

3cm of floatation, but this is too little weight to have the tube float straight (stable buoyancy). Use the attached LHX Battery Optimization Table (p. 56) to calculate optimal battery size.

The optimum battery size with the highest number of successful uplinks is 9 batteries at only 1.14 cm of floatation, and with only 581 successful uplinks, only a bit more than half of the best tag with thinner wall material. This heavier tag with 12 or more pennies would sink. Discuss the implications of this finding: a tag with a thicker wall material and therefore a much deeper maximum depth rating can provide fewer data than a tag with thinner walls and a shallower depth rating.

Figure 1 (above): two PVC tubes, the thicker Schedule 40 tube is shown floating in water. Its bottom is taped closed with clear packing tape, and it is weighed down with pennies as simulated batteries. The thinner 'Type 2" PVC tube is shown outside of the yogurt tub.

RESOURCES

OPB NOVA Buoyancy Basics
http://www.pbs.org/wgbh/nova/lasalle/buoybasics.html

Archimedes Principle
http://library.thinkquest.org/27948/archimede.html

Engineering is Elementary: Science Engineering and Technology
http://www.mos.org/eie/science_engineering.php

Science Buddies: Free Science Fair Project Ideas, Answers, and Tools for Serious Students
http://www.sciencebuddies.org/science-fair-projects/project_engineering.shtml

Teach Engineering: Resources for K-12 (other great links at bottom of page)
http://www.teachengineering.org/engrdesignprocess.php

What is the 12-step design process?
http://wiki.answers.com/Q/What_is_the_12_step_design_process

NATIONAL SCIENCE EDUCATION STANDARDS GRADE 9-12

Content Standard A: Science as Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science
- Structure of atoms
- Structure and properties of matter
- Forces and motion

Content Standard C: Life Science
- Behavior of organisms

Content Standard G: History and Nature of Science
- Science as a human endeavor
- Nature of scientific knowledge

OCEAN LITERACY: ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS

Principle 5. The earth supports a great diversity of life and ecosystems.
Principle 7. The ocean is largely unexplored.

ENGINEERING IN THE OREGON SCIENCE STANDARDS (HIGH SCHOOL)

H.4 Engineering Design: Engineering design is a process of formulating problem statements, identifying criteria and constraints, proposing and testing possible solutions, incorporating modifications based on test data, and communicating the recommendations.

H.4D.1 Define a problem and specify criteria for a solution within specific constraints or limits based on science principles. Generate several possible solutions to a problem and use the concept of trade-offs to compare them in terms of criteria and constraints.

H.4D.2 Create and test or otherwise analyze at least one of the more promising solutions. Collect and process relevant data. Incorporate modifications based on data from testing or other analysis.

H.4D.3 Analyze data, identify uncertainties, and display data so that the implications for the solution being tested are clear.

H.4D.4 Recommend a proposed solution, identify its strengths and weaknesses, and describe how it is better than alternative designs. Identify further engineering that might be done to refine the recommendations.

H.4D.5 Describe how new technologies enable new lines of scientific inquiry and are largely responsible for changes in how people live and work.

H.4D.6 Evaluate ways that ethics, public opinion, and government policy influence the work of engineers and scientists, and how the results of their work impact human society and the environment.

SUPPLEMENTAL MATERIALS LIST

LHX TAG BATTERY SIZE DESIGN WORKSHEET
LHX BATTERY OPTIMIZATION TABLE


15 metres


15 metres

Mark Recapture Table

Trap Number	# Marked	# Unmarked	Total
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
Total number			

Mortality Worksheet

Causes of Mortality	Natural	Man-made	Solution	Risk of Solution	Benefit of Solution

Mortality Worksheet Answer Key

Possible Causes of Mortality	Natural	Man-made	Solution	Risks of Solution	Benefits of Solution
predation	X		none	none	None
pollution		X	decrease sources of pollution	increased regulation	Clean ocean
competition with fisheries for food		X	regulate fisheries	economic impacts	may help Stellers
native harvest		X	reduce/eliminate harvest	cultural impacts	may help Stellers
ship strikes		X	prevent ship strikes	increased costs	may help Stellers
entanglement in fishing gear		X	prevent entanglement	increased costs	reduce unwanted take
changing ocean/climate	X		if natural, none		
changing ocean/climate		X	if human, change behavior	economic impacts	may help Stellers
intentional take		X	change behavior, enforcement	cost of enforcement	may help Stellers
disease	X		research/rehabilitation	cost	unintended impacts
starvation	X		none		
old age	X		none		

LHX Constraint Table

Where they live	**Constraints**	**Why**	**What happens**
in ocean	waterproof	Electronics cannot get wet	tag shorts out
on land	withstand temperature changes	electronics	tag will not work
at cold temperatures	function in the cold	electronics	tag will not work
salty environment	rustproof (non-corrosive)	so it will not rust	Leakage
What they do			
eat, feed on fish	not interfere with feeding	avoid harm to animal	
have young	not interfere with reproduction or birth	avoid harm to animal	
dive (pressure)	be able to withstand high pressure	sea lions dive to 500m	tag explodes
come out on land	be able to withstand pressure changes	can cause tag fatigue	tag breaks
swim	waterproof	Electronics cannot get wet	tag shorts out
LHX goes inside the body			
Shape	no sharp edges or point tips	can harm animal	
Size	not too large	avoid harm to animal	
Materials	compatible with body	avoid harm to animal	toxicity or immune response
LHX Comes out of body			
Appearance	has to be visible by people	So scientists can recover tag	
Buoyancy	must float	to transmit signal to satellite	
Power source	needs batteries	to transmit signal to satellite	

LHX Tag Battery Size Design Worksheet

Data:

Using penny-stacks to simulate batteries, here are "specifications" for each penny:

- 1 copper U.S. penny has a diameter of 19 mm, a height of 1.4 mm, and a mass (weight) of 2.5 grams.
- For the purpose of this exercise, we can assume that each penny can deliver enough current to power an LHX transmitter for 100 transmissions. Therefore, a 1-penny battery can power 100 transmissions, and a 7-penny battery can power 700 transmissions.

Here we use PVC pipe material as the outer shell or 'housing' of our simulated LHX tags.

- The 1" diameter (inner diameter) PVC tubing of the thinner wall variety (called Type 2, as opposed to the much thicker walled 'Schedule 40' pipe) has an outer diameter (O.D.) of 2.67 cm. Therefore the (outer) radius of this pipe is 1.335 cm.

We will use a 12 cm long section of tube to simulate an LHX tag.

- The 12 cm length of type 2, 1" O.D. PVC tubing has a mass (weight) of 22.1 grams (when one end is taped closed with clear packing tape).

Equations:

Equation for calculating the volume of a cylinder of radius r and height h:
[1] $V = r^2 \times Pi \times h$

This can be re-written to solve for height:
[2] $h = V / (r^2 \times Pi)$

Design goals:
Calculate the optimal size of the battery to be used for the LHX tag to get the highest possible number of successful uplinks to a satellite

Design rules and constraints:

In addition to the data given above that states that each penny can power 100 transmissions,
Use the following information:
1. The percentage of transmissions that typically reach a satellite is a function of how much of the upper part of an LHX tag actually floats above water. Specifically:
1.1. At least 1cm of tag has to float above the water level, if less of the tag is exposed, no transmissions will reach a satellite.
1.2. At >= 3.5 cm of exposure, all transmissions (100%) will likely reach a satellite.
1.3. For any exposure above 3.5 cm (more than 3.5 cm show above water) nothing is gained. (We are already at 100%.)
1.4. For each cm less then 3.5, of exposure, there is a 15% penalty in all transmissions that reach the satellite.

LHX BATTERY OPTIMIZATION TABLE

#	total weight of battery (grams)	total weight of tag (grams)	Volume displaced when floating (mL)	height of tag part submerged (cm)	height of tag part exposed (cm)	height exposed >=1cm & up to 3.5	amount of exposure less than 3.5 cm (cm)	% penalty if exposure is < 3.5 cm	total # trans-missions	penalty trans-missions #	uplinks #
8	20	42.1	42.1	7.52	4.48	3.50	0.00	0.00	800	0.00	800.00
9	22.5	44.6	44.6	7.97	4.03	3.50	0.00	0.00	900	0.00	900.00
10	25	47.1	47.1	8.41	3.59	3.50	0.00	0.00	1000	0.00	1000.00
11	27.5	49.6	49.6	8.86	3.14	3.14	0.36	5.38	1100	59.18	1040.82
12	30	52.1	52.1	9.31	2.69	2.69	0.81	12.08	1200	144.93	1055.07
13	**32.5**	**54.6**	**54.6**	**9.75**	**2.25**	2.25	1.25	18.78	1300	244.08	**1055.92** *
14	35	57.1	57.1	10.20	1.80	1.80	1.70	25.47	1400	356.62	1043.38
15	37.5	59.6	59.6	10.64	1.36	1.36	2.14	32.17	1500	482.56	1017.44
16	40	62.1	62.1	11.09	0.91	0.00	0.00	0.00	1600	0.00	0.00
17	42.5	64.6	64.6	11.54	0.46	0.00	0.00	0.00	1700	0.00	0.00
18	45	67.1	67.1	11.98	0.02	0.00	0.00	0.00	1800	0.00	0.00
19	47.5	69.6	69.6	12.43	-0.43	0.00	0.00	0.00	1900	0.00	0.00
20	50	72.1	72.1	12.88	-0.88	0.00	0.00	0.00	2000	0.00	0.00
	Notes: uses weight of 1 penny = 2.5 grams	uses weight of pipe = 22.1 grams	assumes fresh water density = 1	uses equation [2] solved for height	negative values: tag will sink	shows exposure if >1 and up to 3.5	disregards exposure <1 cm	uses 15% penalty value	uses value of 100 transmits per penny	calculates penalty from actual percent	difference

*This is the ideal battery configuration for the LHX tag that results in the largest # of uplinks.

Biology and Ecology of the Steller Sea Lion by Dr. Markus Horning

The Steller sea lion:

The Steller sea lion has the scientific name *Eumetopias jubatus*. The common name was given after the German physician and naturalist Georg Steller who travelled to Alaska on the 1741 Russian expedition led by the Danish-born captain Vitus Bering (after whom the Bering Sea is named). The Steller sea lion is sometimes also called the 'Northern sea lion'. It is the largest of all sea lions, and the largest of the so-called 'eared seals' or scientifically the otariids (the Latin name for 'eared seals'). The 'eared seals are a group of species composed of several different sea lions and also fur seals. Examples of sea lions are the Steller sea lion, the California sea lion, the Galapagos sea lion, the South American sea lion, and others. Examples of fur seals are the Northern fur seal, the Galapagos fur seal, the Antarctic fur seal, and others. All the eared seals have very small external ear 'shells' or 'horns', hence the name 'eared seals'. They are also distinguished by their ability to fold their flippers underneath their body and 'walk' on all four limbs. This way they manage to get around on land quite well. In fact an adult male Steller sea lion can out-run a human quite easily. Generally, however, the eared seals or otariids do not move around on land very much or very fast, and they are really much more at home in the water. Underwater, they are very capable swimmers and divers. Eared seals move through the water by using their fore-flippers very much the way birds use their wings to fly in air. They stroke their fore-flippers up and down to generate forward thrust. These features (ears, articulated flippers and how they swim) set the otariids apart from what we call the 'earless seals' or 'true seals' (or 'phocids' by their Latin name).

True seals include species we can observe along the shores of the Pacific Northwest, such as harbor seals and Northern elephant seals, but also other species such as harp seals, grey seals, ribbon seals and many more. Earless seals only have small holes for their ears; they have no external ear shells. They cannot fold their flippers underneath their bodies, and are therefore much slower on land, only being able to 'wallow' or hobble along with their whole body sliding across sand or rocks. True seals swim by swinging their hind flippers back and forth in sideways motion, very similar to what fish do with their tails. Together with the walrus, the eared seals and the true seals make up the so-called pinnipeds, which is Latin for fin-footed animals. There are about 35 pinnipeds species found in all oceans of the world, and even in some fresh water lakes (like the Lake Baikal seal in Siberia).

Steller sea lions - like all eared seals - exhibit a large degree of 'sexual dimorphism'. Sexual dimorphism means that males and females have different shapes or sizes. In this case the males are much, much bigger than females. Steller sea lion bulls can weigh over 1,200 kg. That's as much as a small car. Females only weigh up to about 300 kg, or only ¼ the weight of adult males. Steller sea lions are found around the rim of the North Pacific Ocean and in the Bering Sea, so in northern California, Oregon, Washington, British Columbia (Canada), Southeast Alaska, the Gulf of Alaska, the Aleutian Island and the Bering Sea, and all the way to the Kamchatka Peninsula and the Sea of Okhotsk, and even all the way to Japan. There used to be well over 300,000 Steller sea lions worldwide, but now there are far fewer of them around (see below). Steller sea lions are very fast swimmers and reasonably good divers. They can remain submerged and hold their breath for 15 minutes or longer (though typically they remain submerged for only 3-5 minutes at a time) and can dive to depths deeper than 500 meters. (If you are wondering about the measurement units I use such as meters and kilograms, that is because in science we only use the so-called International System of Measurements or the SI for short. It is very similar to the metric system.) While these are certainly remarkable feats, they do pale in comparison to what some true seals can accomplish. For example, Northern elephant seal females are known to dive beyond 1,700 meters in depth, and Weddell seals in Antarctica can remain submerged while holding their breath for more than 90 minutes.

Steller sea lions, like most ‘pinnipeds’, are not highly specialized in their diet. They eat a mixed diet of many different fish and ‘cephalopods’ (that refers to squid and octopus). For example, Steller sea lions may eat herring, pollock, Atka mackerel, Pacific mackerel, hake, sandlance, salmon, sturgeon, flatfish such as halibut and various flounders, skates, lampreys, capelin, eulachon, rockfish and various species of squid and octopus. They are not picky, and often adjust their feeding habits to what they can find depending on region or season. However, in many regions where Steller sea lions occur, and during all seasons of the year, Stellers seem to eat pollock.

Like all eared seals, Steller sea lions hunt for fish at sea but return to shore to rest, and also to mate, give birth to their young and to suckle their young. They are after all mammals! We generally can find Stellers in two types of locations on shore. We distinguish between ‘rookeries’ and haul-outs. Rookeries are the breeding colonies where animals mate and females give birth. Haul-outs are areas where the animals rest, but they do not mate or give birth there, though females may suckle their young their. Steller sea lion pups are born between late May and mid-July. Generally, females are thought to have their first pup at the age of five or six years. They only have one pup at a time (singlets, twins have been observed but are extremely rare). Female Steller sea lions suckle their young for long periods of time, typically at least 9-12 months, and often longer than that. In fact, young sea lions even as much as three years old have been observed suckling on their mother. That is rare however, and 12-18 months is probably average. This means that on average, a female Steller sea lion has at most one pup per year, and probably in many cases she does not have a pup every year, but only less often. Females can probably reach an age up to and beyond 30 years, though many die before then. Steller sea lion males follow a very different strategy: they do come ashore as well, but outside of mating do not participate in the raising of their young. Instead, adult males defend a territory, and often engage in fierce fighting with bulls holding neighboring territories. Males typically cannot successfully defend a territory and mate until they are at least 8 or 9 years old, and by the time they are 11 or 12 they may be too worn out and too old. That means they may only have a few mating seasons, and in fact the vast majority of males probably never get to breed. That still works well for the species, because a successful male mates with many females. Males probably don’t get nearly as old as females, and it is hard to find males in the wild that are as old as 18 or 19 years. Infant mortality as in many pinnipeds is high. Probably less than 1/3 of all pups born even reach sexual maturity. This characteristic reproductive behavior with adult males defending territories from May through July, and females giving birth to pups and then mating with males during this same period means that it is much easier to see and observe Steller sea lions during the summer, on their rookeries. Outside of this breeding season, it is more difficult to observe Stellers, and we have to look for them both in the rookeries as well as on haul-outs.

<u>The population decline of the Steller sea lion</u>:

It is estimated that from well over 200,000 animals in 1965, numbers declined to around 45,000 in the first decade of this millennium, in the region within the US from the central Gulf of Alaska all the way to the westernmost Aleutian Islands. During the same time frame, the worldwide population of Steller sea lions declined from well over 300,000 animals to under 100,000. As a result of this dramatic decline, the entire Steller sea lion population was listed as 'threatened' under the U.S. Endangered Species Act in 1990. However, soon scientists recognized that the population decline was limited to only a portion of the Steller's US range. Genetic studies then allowed fisheries managers to recognize two distinct portions of the Steller sea lion population. These are not separate species or subspecies, but instead these management units are called 'stocks' or 'distinct population segments'. The stocks are somewhat arbitrarily split at 144 degrees West Longitude - an imaginary line that runs right through the Gulf of Alaska. From this line to the west all the way along the Alaskan peninsula and the Aleutian Islands we find the western stock (including the central Gulf of Alaska and also the Bering Sea, and we also find western stock on the Russian side of the North Pacific). To the east of this line (including the eastern Gulf of Alaska, Southeast Alaska, British Columbia, Washington, Oregon and Northern California) we find the eastern stock. It is only the western stock that has declined so precipitously over the past four decades. The eastern stock has actually increased steadily during this time. While 35 years ago the western stock far outnumbered animals in the eastern stock, the eastern stock has more than doubled and now we have more animals in the eastern stock than in the US portion of the western stock. As a result of the different population trends (increasing eastern and decreasing western stock), the western population was listed as endangered in 1997, and the eastern stock remained listed as threatened. The fact that the eastern stock is still listed as threatened is being challenged right now, because the eastern stock has never declined, in fact, it has continuously increased over the past 4 decades.

Life History Transmitter Project Background

Scientists use remote sensing technology to study animals in hard-to-reach areas where they cannot easily see them. One example of remote sensing technology is the Life History Transmitter (LHX). This is a special recording device or satellite tag that researchers put inside the body of Steller sea lions to study their life history.

The Steller sea lions once numbered 300,000 worldwide but there are now 75,000 or less individuals. The Western population from the middle of the Gulf of Alaska to Japan is endangered while the Eastern population from the Gulf of Alaska to Northern California is threatened with extinction. Although the population declined many decades earlier, scientists are still uncertain why. Many aspects of marine mammals' lives are a mystery since they spend a good part of their time underwater. Oregon State University researcher, Dr. Markus Horning, developed the Life History Transmitter to find out how Steller sea lions in Alaska are dying and why their population is not recovering.

Veterinarians put this LHX tag into young Steller sea lions. The tag remains free-floating inside the animal's body and records their body temperature throughout the life of the animal. This information is stored in a tiny computer within the tag. Once the animal dies, its temperature drops significantly. (Marine mammals are homeotherms like people and maintain a relatively constant body temperature.) The tag uses the temperature to determine if the animal is dead. Inside the animal's body the tag cannot transmit because the body blocks the signal. The tag must somehow get out of the body to send its information to a satellite. After the animal begins to rot and fall apart, the tag can come out or if the sea lion gets eaten, the tag will fall out. A tag in water will float to the surface. The tag, once it is out of the body, will try to determine if it is in air or water. If the tag is in air on the beach or if it contacts air at the water's surface, it can send its information or data to the satellite.

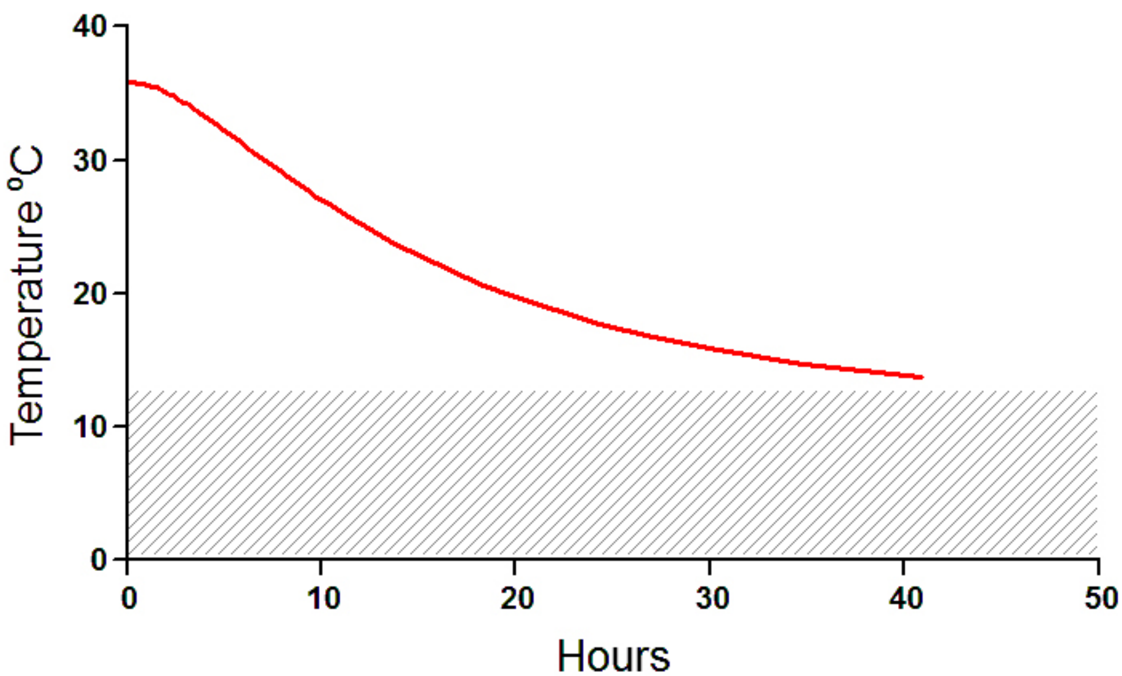
How does the tag tell the scientist how and where Steller sea lions die? They use the temperature of the dying animal to calculate its mass at the time of death and make inferences about how the animal died. Researchers tag young Steller sea lions of a known age, and each tag has a code that gives the animal's identity. Based on the age of the animal, gender, and estimated body condition (weight, body measurements, relative amount of fat and muscle) at the time of death, they can figure out the sea lion's weight at the time of death. Surprisingly, a Steller sea lion's weight can tell a lot about its death.

As the sea lion dies, its body acts as an insulator. It cools slowly and eventually reaches the temperature of seawater or air depending on where the body goes. Meanwhile the tag is still taking temperature measurements. Scientists use the rate at which the body cools to determine the cause of death just like coroners do for humans by using cooling curves. Steller sea lions with a large mass cool more slowly and those with a smaller mass cool more quickly. The cooling rate (temperature over time) gives scientists an indirect measurement of the mass of the dead, sea lion.

The pattern of cooling, sudden or slow and gradual, can also indicate the cause of death. For example, in a Steller sea lion dying of disease or starvation, the body stays intact and cools slowly. If the mass of the animal (based on its cooling curve) is somewhat less than expected, but it still cools slowly, the animal has likely died of starvation or disease that causes weight loss. However, if the tag inside the sea lion experiences a rapid cooling, this indicates the tag has come out of the animal's body. This usually occurs when Orcas eat sea lions as they often tear and shred their prey. If an orca eats a sea lion, but the tag remains inside the body, the body part with the tag will be dramatically smaller and will cool much more rapidly. Unlike an animal that dies of starvation, the cooling curve is sharper.

For example, the scientist receives an email saying "Stella" the Steller sea lion has died. They know that Stella was two years old when she was tagged in 2005. Stella died in 2010. This means Stella is 7 years old. Using the average weight for an adult Steller sea lion female, scientists estimate her weight as 300 kg. Based on that weight and using cooling curves for a given average water or air temperature, scientists can determine it will take hours or days for the body to cool. The difference in the actual cooling curve versus the predicted cooling curve give the mass of the animal upon death. The pattern of cooling abrupt versus slow gives the cause of death.

Here is Stella's actual cooling curve:



Studying the Decline of the Steller Sea Lion: Population Sampling

As a result of this dramatic decline of the Western stock and the listing of the Steller sea lion under the Endangered Species Act scientists at federal agencies like the National Marine Fisheries Service and at Universities have spent a lot of time and effort studying these animals. Researchers have looked at many possible explanations for what might have caused the decline only in the west, and not in the east, and why the western stock is still not recovering. However, it has been very difficult to find out why the western Steller sea lion population has declined so much. Why is it so difficult? These are the main reasons:

1) **Its history**: The decline has happened mostly in the past, when people and scientist were not that interested in the Steller sea lion. No one was paying much attention to what was happening along the Aleutian Islands, and as a result not much information on Steller sea lions was collected. Now the decline is only continuing in the westernmost Aleutian Islands, and the rest of the western stock in the US appears more or less stable at low numbers (though it is not increasing).

2) **Inaccessible**: The western Steller sea lion is mostly found along the Aleutian Islands, and this remote and inhospitable area (to us humans) is very difficult for scientists to reach. Steller sea lions are also very large and dangerous, and as a result it is very hard to capture them and study them. Imagine even trying to get the weight of an animal, since you can't just ask them to step onto a scale.

3) **CSI: no 'corpus delicti'**: *Corpus delicti* is a Latin term used in *crime scene investigations*. A corpus delicti is the object of a crime, for example the dead body in a murder investigation. The decline of the Steller sea lion is almost like a *crime scene investigation* without a *corpus delicti*: scientists hardly ever find bodies of dead sea lions that they might analyze for diseases or evidence of starvation. This is very different from a situation many are familiar with along the West Coast of the U.S. in California, Oregon and even Washington, where every year hundreds and sometimes thousands of seals and sea lions affected by diseases or starvation show up on our beaches. Such starving or sick animals are sometimes cared for by stranded animal rescue networks and rehabilitation centers, but often die on beaches, where researchers sometimes inspect the dead bodies. From samples collected from these dead bodies, scientists may then determine whether the animal died because it was sick or suffered from starvation. Without the bodies of dead Steller sea lions (without the *corpus delicti*), scientists can't easily tell whether diseases or starvation played a major role in the population decline.

4) **Now you see me - now you don't**: the easiest way for us to work with Steller sea lions is to capture animals at the rookeries during the summer time, when the sea lions gather there to breed and the females nurse their young. However, we may be missing out on the animals that are the problem. It could very well be that only healthy animals that are in good shape show up at the rookeries to mate and give birth. Therefore, we may not see sick animals that easily, or maybe not even at all.

As you can see, it is difficult to study the past population decline, but even trying to figure out why the Steller sea lion numbers are not increasing right now is difficult. Given these difficulties, it is maybe not surprising that scientists have not been able to figure out why the western Steller sea lion population collapsed. Scientists have not found a *smoking gun* that would point the finger at any single reason there are now fewer sea lions. For example, researchers have tried to find diseases in the Sea lion population, they have measured the level of pollutants that may reduce the fertility (the ability to have pups) of female sea lions, and they have also looked at the possibility of animals starving or not reproducing as much because they cannot find enough fish - maybe the fishing industry catches too many of the same fish that the sea lions eat. You may remember already reading that Steller sea lions eat a lot of pollock and Atka mackerel. Pollock is a fish that is harvested in huge amounts by very large trawlers in the North Pacific Ocean and the Bering Sea. Trawlers are specialized fishing boats that pull very large fishing nets through the water. The opening of these nets can be as wide as 100 meters (300 feet) or more. Every year, these very large trawlers harvest about 2.5 billion pounds of pollock in the United States. This pollock fishery alone makes up more than one-third of the weight of all fish caught every year in the United States. There are quite a few scientists and fisheries managers that believe that this intense fishing for pollock in Alaskan waters is the main reason Steller sea lions have declined and are not recovering. However, they have very little hard evidence to go by, because it is almost impossible to prove that the sea lions cannot find enough fish just because these big trawlers are collecting so much. Instead, researchers have looked at many other possible reasons for the decline, like diseases and even predation by animals that eat sea lions, such as killer whales and sharks. It is known that sea lions die for many different reasons. Known reasons include death by drowning from getting entangled in old fishing gear and garbage floating at sea (did you know that plastic packing bands are a big problem that kills quite a few sea lions?), death from collisions with large ships such as container transport ships, and death resulting from attacks by animals that eat sea lions. For example, salmon sharks and pacific sleeper sharks are thought to attack and eat sea lions. Killer whales have also been seen attacking and killing sea lions, but killer whales also eat many other marine mammals such as grey whale calves, various species of dolphins, sea otters and harbor seals. Inside of the stomach of a dead killer whale that had washed up on the beach in Prince William Sound in Alaska, scientists found the plastic identification marks that are used by researchers on Steller sea lions (see below). They found tags from at least 14 different Steller sea lion pups that this killer whale had apparently eaten within the past year. Even that however was not considered a smoking gun, since 14 missing sea lions can hardly account for a drop from 200,000 to 45,000 animals, or so researchers thought.

So, researchers have not found any evidence for diseases or other health effects, or large numbers of sea lions being eaten by predators, and have therefore decided that the only possible reason left is the one that is most difficult to prove: lack of fish. But we have to remember that the evidence pointing the finger at lack of fish is very indirect and not very strong. In a jury deliberating evidence from a *Crime Scene Investigation*, it is doubtful whether the lack of evidence could ever result in a conviction.

Given the lack of good answers to this day, what can we do to learn more about these animals in such remote locations, and solve the puzzle of the disappearing sea lions?

<u>Research on the Steller sea lion:</u>

The most important information that scientists and wildlife managers need to have any chance at solving this puzzle is information on how many animals there are, how many are born each year, and how many die each year. That's because quite simply, if more animals die than are born, then the population declines. If more are born than die, then the population increases. If we had things our way, we would also know how each animal dies. How can we do this?

Counting sea lions:

You may already have an idea how we can count sea lions: we can fly along most of the Alaskan coastline and count the animals we see. This is not an easy thing to do, since the coastline of all Aleutian Islands, the Alaskan Peninsula, the Gulf of Alaska and Prince William Sound, all the way down Southeast Alaska towards Canada is much longer than the entire coastline of the rest of the United States combined! That is a lot of flying, a lot of photos, and a lot of counting that has to be done. However, when we add the count of all sea lions from all photos, we still do not have a full count of the whole population. That is because at any given time, many animals are not 'hauled-out', but are instead swimming around in the water, probably looking for fish. In the summer we count more animals than in the winter. This is because the weather for flying and counting is better, but also because the animals spend more time hauled out on rookeries. However, even during the summer when many sea lions meet in the rookeries to mate, give birth, and suckle, many animals are gone. For example, those females that have a pup that is older than a few weeks start to go back in the water for a few hours at first, and for a whole day later in the summer. This is so they can eat enough of the food they need to make milk they feed their pup. Very young pups stays 'at home' in the rookery and patiently await the return of their mom. Older pups also begin to go into the water while their mom is out feeding herself. So, during a small period early in the summer it is possible to count most pups because they don't go into the water yet, but it is impossible to count all older animals at any one time. Counts of animals therefore have to be corrected to account for those that are absent. Because it is so difficult to do a complete aerial survey around the entire North Pacific Rim, scientists only do a complete count about every five years. At other times, scientists only count in a few select areas that are observed more closely. These areas are called '*trend sites*'. However, while it is possible to count most newborn pups in a year, it is much more difficult to figure out how many animals have died from one year to the next, especially when only the counts from trend sites are available. This is for many reasons: animals move around between rookeries and haul-outs. For example, we recently saw an animal at our study location at Sea Lion Caves near Florence on the Oregon coast that was born and marked on Forrester Island in South-East Alaska. Nevertheless, we can get a pretty good idea of the basic sea lion population numbers from these aerial surveys: we can estimate how many there are, how many pups are born, and maybe we can even guess how many animals die from year to year.

Telemetry and the LHX Tag

What is telemetry? Telemetry means 'measuring at a distance'. It is a word composed of the Greek word 'tele', which means distant, and the Greek word 'metros', which means measurement. Telemetry allows us to collect information without being there in person. For example, a webcam is a kind of telemetry that allows us to remotely collect behavioral information, or allows us to remotely read flipper tags or brands, all without being there. The most common application of telemetry on marine mammals is through the use of small electronic devices that are attached to animals and either record information or transmit a signal. While the very first telemetry devices that were used were very simple, mechanical recording devices, modern units are typically very small computers and are in fact very similar to cell phones (smart phones). We call devices that record information without transmitting it 'archival tags' - that's because they create an archive or collection of information. Archival tags usually have a number of different sensors that provide the data these tags record. For example, temperature sensors can tell how cold the water is that animals are swimming through (or how cold the air is if they are 'hauled out'). Pressure sensors can detect how deep underwater an animal is diving. Movement sensors can tell if an animal is sleeping or active. GPS navigation sensors can tell where on the surface of the ocean an animal is located (GPS does not work underwater). Light sensors can tell how much light there is for an animal to see by. And so on... there are many ways to use archival tags to record where an animal is, what it is doing, and what the environment around the animal looks like. For example, if we place an archival tag with a pressure sensor and a movement sensor on a sea lion, once we look at the data such a tag may have recorded over let's say 1 week, we may be able to tell exactly how many dives the sea lion made during this week, how many hours it spent sleeping and how may hours diving at sea, and we can even tell how long and how deep every single dive was that the animal made. We can even tell when the animal was eating fish: we put a very small 'pill' into the stomach of the animal that can sense temperature. This pill transmits the temperature information to the archival tag the animal carries on it's back (more on how we attach tags below). Since a sea lion is a warm-blooded mammal, its stomach is warm, about 37 degrees Celsius (or 98 degrees Fahrenheit). However, the fish that the sea lion eats are cold-blooded, and are at the temperature of the ocean water, much colder, typically about 5 to 10 or at the most 15 degrees Celsius. Therefore, whenever a sea lion eats a fish, the little pill it is carrying in the stomach senses a drop in temperature, and transmits this data to the archival tag on the back of the sea lion.

<u>Getting telemetry data back:</u>
But, how do we get this really interesting and useful data back into our hands? Such archival tags have to be recovered to be able to read the stored information. Usually this means that the animal carrying the tag has to be recaptured again for a second time (the first time was to attach the tag), which may be very difficult. If the tags are not recovered, they are useless. That's why researchers also use transmitting tags (again, very similar to cell phones). The simplest kinds of transmitting tags only transmit one type of signal that is used to find or locate an animal, but they do not transmit any actual data. Fancier tags actually transmit data either in real time (just as it is collected), or data that was previously recorded. Who can receive these transmissions and who can read this data? That depends on the type of system used. For example, some transmitting tags do actually use cell phone systems. That means data transmissions from the tags are picked up by cell phone towers and then sent to the home lab of the scientist as an email or text message. This works well on land, for example when working with moose, elk, or other large land animals. It does not work at sea

because there are no cell phone towers at sea (it does work somewhat in coastal areas). Signals from tags that only transmit a locating signal but no data can be picked up by small hand-held radios (almost like walkie-talkies). This only works over short distances usually less than a mile or two. These types of tags are often used for the purpose of finding an animal, for example for capturing it and recovering an archival tag also attached to the animal. The fanciest types of tags transmit their data to satellites. These tags are incredibly useful as they give us a lot of very valuable information on the animal carrying the tag, but without the need to run around with hand-held receivers, and without having to recapture the animal and recover the tag. Tags that transmit their data directly to satellites also work with animals that are at sea anywhere on the planet.

How do we attach archival or transmitting tags to animals?

There are several ways we can attach tags to animals, include using suction cups on smooth-skinned whales, or using a small collar or harness like those used on dogs. However, these methods don't work well on seals, sea lions or diving birds. They are so streamlined that any collar would fall off. Instead, we glue the tags directly to the fur (for seals and sea lions) or feather (for diving birds like penguins). We use 5-minute epoxy from the local hardware store for this. The glue firmly attaches the tags to the hair or feather, and the tags stay on for many weeks or months in a way that does not harm the animal. However, the tags do not stay on forever since all these animals molt once per year. When they molt they change their fur or feather coat: old hair or feathers fall out and are replaced by new ones. At this time, any tags glued on simply fall off with the old fur or feathers. This is good because it means we don't bother the animals for too long, but it is also bad because it means we can never follow an animal or record its behavior for more than 12 months at the most, often times for much less than that, depending on when during the year we can capture them. So, by using telemetry devices we can learn a lot about the behavior and activities of marine animals at sea, when we cannot directly observe them. But can we use telemetry to monitor animals for periods longer than 12 months?

Implanted telemetry devices:

To get around the problems with tags glued to fur or feathers falling off at the most after 6-12 months, researchers have started using surgically implanted tags. An implanted tag is a device that is inserted inside of the body of an animal. Most people have probably heard of microchips that are used for pet identification. These so-called PIT-tags (that stands for Passive Implantable Transponder) are very small - typically the size of a large grain of rice - and are inserted under the skin of a dog or cat using a syringe-needle applicator. PIT-tags can be so small because they don't have heir own battery. Instead, they get their energy from what is called an 'interrogator', a scanner/reader device that looks like a large wand similar to those used for hand-held airport security screening. Such a reader wand is waved over the body of an animal, and in doing so emits electromagnetic energy that a special device can pick up and use. The device can then respond by emitting a very low power signal in return. If the reader wand receives a response from a PIT tag it will display information such as serial number, and sometimes even temperature. PIT tags have the big disadvantage that the reader wand needs to pass within a few inches of the tag to pick up a signal, because the tags have to use very little energy as a result of not having their own battery. To transmit a signal over a greater distance, a battery is needed, and generally, the longer the distance once tries to cover the bigger the battery has to be. That's why externally attached tags that need to transmit up to a satellite (over great distances of hundreds of kilometers) often have very large batteries, the size of flashlight batteries. We can even implant such large devices into large animals, but they can no longer be simply inserted under the skin through a syringe needle. Instead, we have to surgically implant such larger tags in an operation on a fully anesthetized animal. Different types of implanted telemetry tags have been used for a long time, and on many different animals. The first few applications used very small, short-range temperature transmitters in laboratory rats, and also in wild rodents. For such small animals, the batteries had to be very small, and as a result the transmitting range and life span were both very short. These tags were only able to transmit a signal over a few tens of meters, for maybe up to four weeks. Now larger tags are used in larger animals that last longer and can transmit over greater distances. Archival tags that record data are also implanted, but these have the big disadvantage of once again requiring recapture and even a second surgery to remove the implanted device, to get to the stored data. Unfortunately, implanted transmitting tags are faced with the fact that the host body weakens the signal substantially. For example, while many external telemetry devices exist that can successfully communicate with satellites over a distance of hundreds of kilometers, currently no implanted devices are capable of sending a strong enough signal to reach a satellite.

The Life History Transmitter - a new idea:

This is where the Life History Transmitter (or in short the LHX tag) comes in. I specifically developed the concept of this highly specialized telemetry transmitter for the purpose of helping us address the many questions surrounding the past and present population trends in the Steller sea lion. I wanted a telemetry device that could give us very specific information on individual Steller sea lions over the course of many years, and no matter where the animals might be and what might happen to them. I specifically wanted information on how long individual animals live, where they die, and how they die. Most of all, I was interested in finding out how many of them die from predation by sharks or killer whales. In other words, I wanted data from the missing '*corpus delicti*'. Two of these requirements were seemingly in contradiction with one another: multi-year tagging, and unlimited coverage (that means we get data back reliably no matter where on the planet the animal is located). Pretty much the only way to get unlimited coverage is through satellite data links. The only way to get multi-year tag retention is through implanted tags. However, we cannot transmit data to satellites from implanted devices that have a reasonable size.

The solution: delayed transmission, archival satellite transmitters:

The solution to this problem lay in the idea of using a tag that first works as an implanted archival tag while the animal is alive, and then works as an external transmitting tag after the animal has died. How can that work? This implanted archival tag has a satellite transmitter that only begins to transmit to satellites after it has come out of the host animal's body, after the animal has died. LHX tags are designed to work for many, many years. They should work for 10 years and longer. They are implanted into the gut cavity of the host sea lion (the belly). There they monitor several sensors and record data from these sensors, but they don't even attempt to transmit. The LHX tags also try to determine the state of the host animal: is it alive, or has it died? Once a tag has determined that the animal has died, it switches into a different mode of operation. It now tries to determine whether it has come out of the body of the dead host animal. The idea is that this '*extrusion*' should happen through a number of natural processes. Most likely, the body of a dead animal will decompose. This process may also be accelerated through scavengers that consume portions of the carcass. For example, in the oceans there are many scavenging organisms, such as worms, crustaceans, but also some fish. Along the shore, other scavengers may contribute to the process, such as vultures, eagles, foxes, rodents, crabs, insects and others. Once the decomposition process is sufficiently advanced, the remains of the body fall apart and the LHX tag falls out. If this happens underwater, the LHX tag will float to the surface of the ocean, since it is lighter than water (it floats or is 'positively buoyant'). At this point, the LHX tag will recognize that it has come out of the host animal's body, and that it is at the surface of the ocean or lying on a beach. That's when it starts to transmit all the data it has previously stored through the life of the animal. Now that the tag is outside of the body the signal is strong enough to reach an orbiting satellite. Once we receive this data back from the satellite (via email), we know that the animal carrying the tag has died, when it died, where it died, what it did throughout its whole life, and maybe even why it died. So, we may not hear from a tag for many years, but once we do, we get some amazing data we could not get by any other means, no matter where the animal may have moved and where or when it might have died - in other words, we will eventually get data no matter what might have happened to the '*corpus delicti*'.

How about if the host animal was killed by a shark and eaten (if the '*corpus delicti*' was consumed)? Three things could happen: most predators like sharks and killer whales do not swallow large prey such as sea lions whole. Instead, they tear them apart and eat the bits and pieces one at a time. There is a good chance the LHX tags will come flying out of the killed sea lions body as the predator tears it apart. The tags are designed to remain 'free-floating': they have a special coating that prevents connective tissue from sticking to the tag. This makes it more likely the tags will come flying out and won't get swallowed by the predator. However, it is also possible that a predator does swallow an LHX tag. In that case, it will likely pass through the digestive tract of the predator and be passed out with other excrements, or it may be thrown up. We know this is what happens to the stomach temperature pills. In this case the tag would eventually still end up outside floating on the water from where it would begin transmissions. There is of course a slight possibility that the predator just happens to bite down on a tag, and it may crush it. In that case, the tag is destroyed and we won't hear from it.

<u>Challenges in using LHX tags:</u>
That is the biggest problem with the use of LHX tags: if we don't hear from a tag, we cannot really tell whether the animal carrying the tag is still alive, or whether it maybe died and the tags were unable to uplink to a satellite. There are several reasons why a tag may be unable to uplink to a satellite: a predator may have crushed it or it may have suffered some internal failure. All electronic devices can fail; batteries can run down, software can malfunction. However, even a tag that works without a flaw just as planned may be unable to uplink to a satellite if it is stuck under a rock somewhere, or is covered by algae. How do we deal with this problem?

<u>Two is better than one:</u>
The best way to deal with this problem is to use two LHX tags for each animal. For starters, this dramatically increases the probability that we will hear from at least one of the two tags. However, what's even more important is that we can now actually estimate how likely it will be that a tag will be unable to uplink to a satellite. If all study animals are released with two LHX tags, then if all goes well we will hear from both tags if an animal dies - we call this a dual data return. In a number of cases - hopefully a small number - we will hear from only one of the two tags in what we call a single data return. In an unknown number of cases we will hear from neither tag (we might call this a dud). By comparing the number of single returns to the number of dual returns we can actually estimate how many duds may have happened. Obviously, we need to have a reasonably large number of returns to be able to come up with these estimates.

Carcass testing:
To get the required numbers, we actually do what we call '*carcass testing*'. Basically we are simulating mortalities, but for obvious reasons we don't do that with live animals. Instead, we use the bodies of animals that have already died (these are called *carcasses*). We get them from our regional stranded animal response network (like the Oregon Marine Mammal Stranding Network, check out their website at http://mmi.oregonstate.edu/ommsn). Then we insert two LHX tags into the carcass, just like we would in a live animal. Then we deposit the carcass on a beach, or take it out to sea in a boat and drop it overboard. In this case, we know that the animal has already died (it did so before we ever got to work with it), and also where (where we deposited the carcass). Then we have to wait and see how long it takes before we hear from one or both of the LHX tags. Most people are surprised by how quickly the decomposition process happens that 'releases' the tags from the decomposing carcasses. Of course this depends on many factors like location, temperature, weather, and what scavengers might be there. In our carcass testing, we have seen LHX tag releases in just over 2 weeks, and some have taken as long as ten weeks. On average, the tags were released within a little over one month. From our carcass testing and actual live animal returns, we now have a pretty good idea how many of the LHX tags may be unable to uplink, and how many events we may have missed:

How reliably do LHX tags work?
Currently we are estimating that about 1 in 10 LHX tags that were extruded from a dead body cannot uplink to a satellite. We do not know why about 10% of the tags don't uplink, since this value is a combination of possible technical failures of a tag (for example a dead battery), a tag being destroyed by a predator in an attack, or a tag getting stuck somewhere where it cannot reach any satellite. That is actually a pretty good result, given the many challenges in making tags that work reliably under such difficult conditions. Even with external tags we are very happy if we get a data return rate of 75%, so 90% is just peachy! This also means that for dual LHX tag deployments, we will very likely only miss 1 in 100 mortalities, or the other way around, we have a 99% likelihood of actually getting data back if an animal dies. This is a much higher success rate than for conventional telemetry projects, probably for two reasons: 1) I have spent a lot of time and effort together with the company making these tags (Wildlife Computers) to make sure these tags are as reliable as they can possibly be, and 2) the use of two tags in each animal does make a big difference (the difference between 90% and 99% success).

What can we learn from the data we receive from LHX tags after animals have died?
The most important bit of information we receive from the tags is simply the confirmation that the animal has died. But we get more data than that: we find out exactly when the animal has died, to within 30 minutes. That is because LHX tags have temperature sensors that tell them when the host animal is still alive (it is warm). Once a warm-blooded animal dies, it's body core temperature begins to drop, and this pretty much starts as soon as the animal is dead, unless the dead body is in a very warm environment (our sea lions are in a very cold environment). The LHX tags sense this drop in temperature and record the time and date when it happens. That way, even if the tags don't begin to transmit for weeks or even months, we know exactly when the animal died. This same technique is used in police *crime scene investigations*. That's how a medical examiner may estimate when a crime victim may have actually died, even if the body was only found several hours later. The examiner will take a number of measurements, including the ambient air temperature, the body mass (weight) of the body and the temperature inside of the dead body. Knowing that the body must have started at 37 degrees Celsius (or 98 degrees Fahrenheit), the examiner

can then calculate how long it must have taken for the body to drop to the current temperature inside of the body. This only works if death did not occur too long before the measurements were done.

This is a huge difference in terms of the data quality compared to a marked-animal observation study, if observations like counts are only conducted once per year, as is the case with sea lions in Alaska. If you only check on who is alive once per year, and you don't see a specific marked individual, it might have died, but you don't know when. You only know that it died sometime between two observations. If for example two observations were done on August 1st, but 12 months apart (once in 2009 and once in 2010), then you can only say the animal died sometime between these two dates, on any of the 364 days between them. Plus, you cannot even be sure if the animal did in fact die, it may have simply moved outside of the observation area. With LHX tags, we know exactly on which day and even in which hour of the day an animal died, no matter where it died.