Sea Shell Science

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Debby West
Science Teacher
Medea Creek Middle School
1002 Doubletree Road
Oak Park, CA 91377

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From pearls to high performance materials, the material science behind seashells and the biomineralization process holds much to be discovered. Links between the interdisciplinary science of marine biotechnology and the California State Science Standards are clearly evident and will be presented with references to current research and discoveries.

Presented by Debby West
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Materials Research

"The products of modern material research impact our economy and our everyday lives. Materials research centers address fundamental science and engineering problems in the creation of new materials. They also provide students a highly interdisciplinary education that is prized by potential employers in industry, academia and government."

Thomas Weber
Director of NSF's Division of Materials Research

UCSB Materials Research Lab

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Research Project

Project Title: Examination of protein roles in aragonite crystal growth of abalone shells

Background: The abalone shell (Haliotis rufasin) is a highly elastic lightweight solid composite consisting of 98% $CaCO_3$ and 2% organic polymer adhesive (proteins.)

Experimental purpose:

Part I - Determine the role of temperature on crystal growth of calcite

Part II - Determine the role of various abalone shell proteins on crystal morphology.

Procedure:

Data: Part I – Data indicated cooler temperatures (4^oC – 14^oC) give rise to higher quality calcite crystals.

Part II – Polarized light and SEM data showed different crystal morphology with different proteins and controls showed no overgrowth.

Conclusion: Crystal growth is affected differently by different proteins. What we want to know is the role individual proteins play in the crystal growth process. Atomic force microscopy is a new gate to go through in observing different growth patterns.

Thanks and appreciation are extended to Fiona Goodchild, Dan Morse, Martina Michenfelder and James Weaver as well as others from NSF, MRL and MSI for their sponsorship, coordination, time, support, instruction and assistance.

What is Biomineralization?

Biomineralization refers to the process by which living organisms form inorganic solids. Examples are everywhere, from bones and teeth to natural pearls and sea shells, to the small magnetic particles formed by magnetotactic bacteria. Frequently these biominerals are formed at organic interfaces. The remarkable control that nature exerts over a crystal's size, shape, and crystallographic orientation is striking, and the properties of the resulting materials such as high strength, resistance to fracture, and aesthetic value serve as goals for scientists to achieve in the laboratory. We approach this topic from two points of view. First, we try to learn more about the natural processes by investigating a specific example, the formation of calcium carbonate at organic interfaces. Second, we use some of what nature has shown us to design the synthesis of inorganic particles for materials applications.

Biomineralization at UCSB

http://lifesci.ucsb.edu/MCDB/faculty/morse/morse.htm

Applications of Research

http://www.msi.ucsb.edu/ResHi/text/apps/Morse/Morse.htm

Other Biomineralization Research Applications

Bone is formed by stress-induced precipitation of hydroxyapatite on an organic (collagen) matrix scaffolding.

The biomineral calcium oxalate monohydrate (COM) is a major component of urinary stones, which are not pleasant. An understanding of the processes that lead to COM precipitation in the urinary tract could lead to the prevention or treatment of urinary stone disease.

Shell Formation in Gastropods
http://www.humbolt1.com/~apc2/shell.htm

Shells to Standards

Earth Science

"Rocks are the pages of Earth's diary, and fossils are the words on the pages, recounting surprising details of the history of life."

Rocks are the foundation upon which civilizations are built. With phrases like "solid as a rock" and "firm as the earth beneath our feet" we sometimes view the Earth as unchanging and stable. Far from stable, the Earth is a dynamic place, constantly changing, moving, and being dramatically changed. Geology is the science of rocks. Rocks reveal the immense history of Earth and give us a new perspective on our place in nature.

Paleontology as a science looks at fossil remains of ancient organisms turned to stone reminding us of our recent arrival in the history of life.

Because rocks are made of minerals and fossils are mineralized remains of once living things we can begin our study with minerals. This will also lay the foundation for understanding biomineralization.

Lesson 1 Minerals of the Earth – A mineral is a naturally occurring, inorganic solid that has a crystal structure and a definite chemical composition. Minerals are the building blocks of rocks. They have a unique set of properties and can be identified using a series of standardized tests. The forming of mineral crystals is one of the constructive processes that is continuous in the Earth's crust.
http://student.biology.arizona.edu/sciconn/earthscience/mineralstext.html

Lesson 2 – Mighty Minerals
http://sciencespot.net/Pages/classearth.html

Lesson #3 - Mineral Mania
http://sciencespot.net/Pages/classearth.html

Calcium in the biomineralization process

Calcium is one mineral used by the abalone to build its shell. You too use calcium to build strong bones and teeth. These processes involve biomineralization.
What can Calcium Carbonate be used for?
What is a carbonate and what is it used for?

Lesson 4 - Rock Hounds

Minerals are the building blocks of rocks. The Earth's crust, the moon and planets are made of rock. This web-based activity explains the rock cycle and how rocks form.
http://www.fi.edu/fellows/payton/rocks/lesson.htm

Fossils
Studying Fossils

Lesson 5- It's All In The Rocks

Lesson 6- Shells on the Mountain Top?

State Standards

Plate Tectonics and Earth's Structure

1. **Plate tectonics explains important features of the Earth's surface and major geologic events.**
   As the basis for understanding this concept, students know:
   a. the fit of the continents, location of earthquakes, volcanoes, and midocean ridges, and the distribution of fossils, rock types, and ancient climatic zones provide evidence for plate tectonics.
2. **Topography is reshaped by weathering of rock and soil and by the transportation and deposition of sediment.**
   As the basis for understanding this concept, students know:
   b. rivers and streams are dynamic systems that erode and transport sediment, change course, and flood their banks in natural and recurring patterns.

Ecology (Life Science)

5. Organisms in ecosystems exchange energy and nutrients among themselves and with the environment.
As a basis for understanding this concept, students know:
b. over time, matter is transferred from one organism to others in the food web, and between organisms and the physical environment.

6. Sources of energy and materials differ in amounts, distribution, usefulness, and the time required for their formation.
As a basis for understanding this concept, students know:
b. different natural energy and material resources, including air, soil, rocks, minerals, petroleum, fresh water, wildlife, and forests, and classify them as renewable or nonrenewable.
c. natural origin of the materials used to make common objects.

Investigation and Experimentation

7. Scientific progress is made by asking meaningful questions and conducting careful investigations.
As a basis for understanding this concept, and to address the content the other three strands, students should develop their own questions and perform investigations. Students will:
b. select and use appropriate tools and technology (including calculators, computers, balances, spring scales, microscopes, and binoculars) to perform tests, collect data, and display data

Life Science

Lesson 7– Mineral Elements Necessary for Life
http://www.thecatalyst.org/forum/enlp.html

Classification
Lesson 8– Seashell Discovery: A Lesson in Inductive Classification
http://ousdmail.k12.ca.us/~codypren/Sea_shells.html

Lesson 9– Learning From the Fossil Record
Paleontologists, geologists, biologists, and others use the fossil record to learn about the past history of the Earth. With this knowledge we have gained an understanding of geologic processes that continue today, biodiversity past and present, species origination and extinction, past and present climates, oceans, and atmospheres among other things.
http://www.ucmp.berkeley.edu/fosrec/Learning.html – Contents of links to lessons and information
http://www.ucmp.berkeley.edu/fosrec/ScotchmoorFossil.html Introduction and connections to standards

Lesson 10– A Peek At The Past Fossil Patterns: Gradualism vs Punctuated Equilibria

Lesson 11– The Great Fossil Find
Students are taken on an imaginary fossil hunt and attempt to reconstruct their creature. Their interpretation of the creature changes as new pieces are found.
http://www.indiana.edu/~ensiweb/lessons/gr.fs.fd.html

Structure and Function in Living Systems
Anatomy and physiology of Mollusks
Gastropods
Abalone Guide

State Standards

3. Biological evolution accounts for the diversity of species developed through gradual processes over many generations.
As a basis for understanding this concept, students know:
a. both genetic variation and environmental factors are causes of evolution and diversity of organisms.
b. the reasoning used by Darwin in making his conclusion that natural selection is the mechanism of evolution.
c. how independent lines of evidence from geology, fossils, and comparative anatomy provide a basis for the theory of evolution.
d. how to construct a simple branching diagram to classify living groups of organisms by shared derived characteristics, and expand the diagram to include fossil organisms.
e. extinction of a species occurs when the environment changes and the adaptive characteristics of a species are insufficient for its survival.

Physical Science

Crystal Chemistry

Chemistry of Calcium
Mineral Properties

States of Matter

Bonding in Mineral Crystals

Crystal Growth in Space

State Standards

3. Elements have distinct properties and atomic structure. All matter is comprised of one or more of over 100 elements.

As a basis for understanding this concept, students know:

a. the structure of the atom and how it is composed of protons, neutrons and electrons.

b. compounds are formed by combining two or more different elements. Compounds have properties that are different from the constituent elements.

c. atoms and molecules form solids by building up repeating patterns such as the crystal structure of NaCl or long chain polymers.

d. the states (solid, liquid, gas) of matter depend on molecular motion.

e. in solids the atoms are closely locked in position and can only vibrate, in liquids the atoms and molecules are more loosely connected and can collide with and move past one another, while in gases the atoms or molecules are free to move independently, colliding frequently.

f. how to use the Periodic Table to identify elements in simple compounds.

Chemistry of Living Systems (Life Science)

6. Principles of chemistry underlie the functioning of biological systems.

As a basis for understanding this concept, students know:

a. carbon, because of its ability to combine in many ways with itself and other elements, has a central role in the chemistry of living organisms.

b. living organisms are made of molecules largely consisting of carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur.

c. living organisms have many different kinds of molecules including small ones such as water and salt, and very large ones such as carbohydrates, fats, proteins and DNA.

Appendix A - Standards
6th Grade Science Content Standards

Focus on Earth Science

Plate Tectonics and Earth's Structure

1. Plate tectonics explains important features of the Earth's surface and major geologic events.

As the basis for understanding this concept, students know:

a. the fit of the continents, location of earthquakes, volcanoes, and midocean ridges, and the distribution of fossils, rock types, and ancient climatic zones provide evidence for plate tectonics.

b. the solid Earth is layered with cold, brittle lithosphere; hot, convecting mantle; and dense, metallic core.

c. lithospheric plates that are the size of continents and oceans move at rates of centimeters per year in response to movements in the mantle.

d. earthquakes are sudden motions along breaks in the crust called faults, and volcanoes/fissures are locations where magma reaches the surface.

e. major geologic events, such as earthquakes, volcanic eruptions, and mountain building result from plate motions.

f. how to explain major features of California geology in terms of plate tectonics (including mountains, faults, volcanoes).

g. how to determine the epicenter of an earthquake and that the effects of an earthquake vary with its size, distance from the epicenter, local geology, and the type of construction involved.

Shaping the Earth's Surface

2. Topography is reshaped by weathering of rock and soil and by the transportation and deposition of sediment.

As the basis for understanding this concept, students know:

a. water running downhill is the dominant process in shaping the landscape, including California's landscape.

b. rivers and streams are dynamic systems that erode and transport sediment, change course, and flood their banks in natural and recurring patterns.

c. beaches are dynamic systems in which sand is supplied by rivers and moved along the coast by wave action.

d. earthquakes, volcanic eruptions, landslides, and floods change human and wildlife habitats.

Heat (Thermal Energy) (Physical Science)

3. Heat moves in a predictable flow from warmer objects to cooler objects until all objects are at the same temperature.

As a basis for understanding this concept, students know:

a. energy can be carried from one place to another by heat flow, or by waves including water waves, light and sound, or by moving objects.

b. when fuel is consumed, most of the energy released becomes heat energy.

c. heat flows in solids by conduction (which involves no flow of matter) and in fluids by conduction and also by convection (which involves flow of matter).

d. heat energy is also transferred between objects by radiation; radiation can travel through space.

Energy in the Earth System

4. Many phenomena on the Earth's surface are affected by the transfer of energy through radiation and convection currents.

As a basis for understanding this concept, students know:

a. the sun is the major source of energy for phenomena on the Earth's surface, powering winds, ocean currents, and the water cycle.

b. solar energy reaches Earth through radiation, mostly in the form of visible light.

c. heat from Earth's interior reaches the surface primarily through convection.

d. convection currents distribute heat in the atmosphere and oceans.

e. differences in pressure, heat, air movement, and humidity result in changes of weather.

Ecology (Life Science)

5. Organisms in ecosystems exchange energy and nutrients among themselves and with the environment.

As a basis for understanding this concept, students know:

a. energy entering ecosystems as sunlight is transferred by producers into chemical energy through photosynthesis, and then from organism to organism in food webs.

b. over time, matter is transferred from one organism to others in the food web, and between organisms and the physical environment.

c. populations of organisms can be categorized by the functions they serve in an ecosystem.

d. different kinds of organisms may play similar ecological roles in similar biomes.

e. the number and types of organisms an ecosystem can support depends on the resources available and abiotic factors, such as quantity of light and water, range of temperatures, and soil composition.

Resources

6. Sources of energy and materials differ in amounts, distribution, usefulness, and the time required for their formation.

As a basis for understanding this concept, students know:

a. the utility of energy sources is determined by factors that are involved in converting these sources to useful forms and the consequences of the conversion process.

b. different natural energy and material resources, including air, soil, rocks, minerals, petroleum, fresh water, wildlife, and forests, and classify them as renewable or nonrenewable.

c. natural origin of the materials used to make common objects.

Investigation and Experimentation

7. Scientific progress is made by asking meaningful questions and conducting careful investigations.

As a basis for understanding this concept, and to address the content the other three strands, students should develop their own questions and perform investigations. Students will:

a. develop a hypothesis.

b. select and use appropriate tools and technology (including calculators, computers, balances, spring scales, microscopes, and binoculars) to perform tests, collect data, and display data.

c. construct appropriate graphs from data and develop qualitative statements about the relationships between variables.

d. communicate the steps and results from an investigation in written reports and verbal presentations.

e. recognize whether evidence is consistent with a proposed explanation.

f. read a topographic map and a geologic map for evidence provided on the maps, and construct and interpret a simple scale map.

g. interpret events by sequence and time from natural phenomena (e.g., relative ages of rocks and intrusions).

h. identify changes in natural phenomena over time without manipulating the phenomena (e.g., a tree limb, a grove of trees, a stream, a hillslope).

7th Grade Science Content Standards

Focus on Life Science

Cell Biology

1. All living organisms are composed of cells, from just one to many trillions, whose details usually are visible only through a microscope.

As a basis for understanding this concept, students know:

a. cells function similarly in all living organisms.

b. the characteristics that distinguish plant cells from animal cells, including chloroplasts and cell walls.

c. the nucleus is the repository for genetic information in plant and animal cells.

d. mitochondria liberate energy for the work that cells do, and chloroplasts capture sunlight energy for photosynthesis.

e. cells divide to increase their numbers through a process of mitosis, which results in two daughter cells with identical sets of chromosomes.

f. as multicellular organisms develop, their cells differentiate.

Genetics

2. A typical cell of any organism contains genetic instructions that specify its traits. Those traits may be modified by environmental influences.

As a basis for understanding this concept, students know:

a. the differences between the life cycles and reproduction of sexual and asexual organisms.

b. sexual reproduction produces offspring that inherit half their genes from each parent.

c. an inherited trait can be determined by one or more genes.

d. plant and animal cells contain many thousands of different genes, and typically have two copies of every gene. The two copies (or alleles) of the gene may or may not be identical, and one may be dominant in determining the phenotype while the other is recessive.

e. DNA is the genetic material of living organisms, and is located in the chromosomes of each cell.

Evolution

3. Biological evolution accounts for the diversity of species developed through gradual processes over many generations.

As a basis for understanding this concept, students know:

a. both genetic variation and environmental factors are causes of evolution and diversity of organisms.

b. the reasoning used by Darwin in making his conclusion that natural selection is the mechanism of evolution.

c. how independent lines of evidence from geology, fossils, and comparative anatomy provide a basis for the theory of evolution.

d. how to construct a simple branching diagram to classify living groups of organisms by shared derived characteristics, and expand the diagram to include fossil organisms.

e. extinction of a species occurs when the environment changes and the adaptive characteristics of a species are insufficient for its survival.

Earth and Life History (Earth Science)

4. Evidence from rocks allows us to understand the evolution of life on Earth.

As the basis for understanding this concept, students know: a. Earth processes today are similar to those that occurred in the past and slow geologic processes have large cumulative effects over long periods of time.

b. the history of life on Earth has been disrupted by major catastrophic events, such as major volcanic eruptions or the impact of an asteroid.

c. the rock cycle includes the formation of new sediment and rocks. Rocks are often found in layers with the oldest generally on the bottom.

d. evidence from geologic layers and radioactive dating indicate the Earth is approximately 4.6 billion years old, and that life has existed for more than 3 billion years.

e. fossils provide evidence of how life and environmental conditions have changed.

f. how movements of the Earth's continental and oceanic plates through time, with associated changes in climate and geographical connections, have affected the past and present distribution of organisms.

g. how to explain significant developments and extinctions of plant and animal life on the geologic time scale.

Structure and Function in Living Systems

5. The anatomy and physiology of plants and animals illustrate the complementary nature of structure and function.

As a basis for understanding this concept, students know:

a. plants and animals have levels of organization for structure and function, including cells, tissues, organs, organ systems, and the whole organism.

b. organ systems function because of the contributions of individual organs, tissues, and cells. The failure of any part can affect the entire system.

c. how bones and muscles work together to provide a structural framework for movement.

d. how the reproductive organs of the human female and male generate eggs and sperm, and how sexual activity may lead to fertilization and pregnancy.

e. the function of the umbilicus and placenta during pregnancy.

f. the structures and processes by which flowering plants generate pollen and ovules, seeds, and fruit.

g. how to relate the structures of the eye and ear to their functions.

Physical Principles in Living Systems (Physical Science)

6. Physical principles underlie biological structures and functions.

As a basis for understanding this concept, students know:

a. visible light is a small band within a very broad electromagnetic spectrum.

b. for an object to be seen, light emitted by or scattered from it must enter the eye.

c. light travels in straight lines except when the medium it travels through changes.

d. how simple lenses are used in a magnifying glass, the eye, camera, telescope, and microscope.

e. white light is a mixture of many wavelengths (colors), and that retinal cells react differently with different wavelengths.

f. light interacts with matter by transmission (including refraction), absorption, or scattering (including reflection).

g. the angle of reflection of a light beam is equal to the angle of incidence.

h. how to compare joints in the body (wrist, shoulder, thigh) with structures used in machines and simple devices (hinge, ball-and-socket, and sliding joints).

i. how levers confer mechanical advantage and how the application of this principle applies to the musculoskeletal system.

j. contractions of the heart generate blood pressure, and heart valves prevent backflow of blood in the circulatory system.

Investigation and Experimentation

7. Scientific progress is made by asking meaningful questions and conducting careful investigations.

As a basis for understanding this concept, and to address the content the other three strands, students should develop their own questions and perform investigations. Students will:

a. select and use appropriate tools and technology (including calculators, computers, balances, spring scales, microscopes, and binoculars) to perform tests, collect data, and display data.

b. utilize a variety of print and electronic resources (including the World Wide Web) to collect information as evidence as part of a research project.

c. communicate the logical connection among hypothesis, science concepts, tests conducted, data collected, and conclusions drawn from the scientific evidence.

d. construct scale models, maps and appropriately labeled diagrams to communicate scientific knowledge (e.g., motion of Earth's plates and cell structure).

e. communicate the steps and results from an investigation in written reports and verbal presentations.

8th Grade Science Content Standards

Focus on Physical Science

Motion

1. The velocity of an object is the rate of change of its position.

As a basis for understanding this concept, students know:

a. position is defined relative to some choice of standard reference point and a set of reference directions.

b. average speed is the total distance traveled divided by the total time elapsed. The speed of an object along the path traveled can vary.

c. how to solve problems involving distance, time, and average speed.

d. to describe the velocity of an object one must specify both direction and speed.

e. changes in velocity can be changes in speed, direction, or both.

f. how to interpret graphs of position versus time and speed versus time for motion in a single direction.

Forces

2. Unbalanced forces cause changes in velocity.

As a basis for understanding this concept, students know:

a. a force has both direction and magnitude.

b. when an object is subject to two or more forces at once, the effect is the cumulative effect of all the forces.

c. when the forces on an object are balanced, the motion of the object does not change.

d. how to identify separately two or more forces acting on a single static object, including gravity, elastic forces due to tension or compression in matter, and friction.

e. when the forces on an object are unbalanced the object will change its motion (that is, it will speed up, slow down, or change direction).

f. the greater the mass of an object the more force is needed to achieve the same change in motion.

g. the role of gravity in forming and maintaining planets, stars and the solar system.

Structure of Matter

3. Elements have distinct properties and atomic structure. All matter is comprised of one or more of over 100 elements.

As a basis for understanding this concept, students know:

a. the structure of the atom and how it is composed of protons, neutrons and electrons.

b. compounds are formed by combining two or more different elements. Compounds have properties that are different from the constituent elements.

c. atoms and molecules form solids by building up repeating patterns such as the crystal structure of NaCl or long chain polymers.

d. the states (solid, liquid, gas) of matter depend on molecular motion.

e. in solids the atoms are closely locked in position and can only vibrate, in liquids the atoms and molecules are more loosely connected and can collide with and move past one another, while in gases the atoms or molecules are free to move independently, colliding frequently.

f. how to use the Periodic Table to identify elements in simple compounds.

Earth in the Solar System (Earth Science)

4. The structure and composition of the universe can be learned from the study of stars and galaxies, and their evolution.

As a basis for understanding this concept, students know:

a. galaxies are clusters of billions of stars, and may have different shapes.

b. the sun is one of many stars in our own Milky Way galaxy. Stars may differ in size, temperature, and color.

c. how to use astronomical units and light years as measures of distance between the sun, stars, and Earth.

d. stars are the source of light for all bright objects in outer space. The moon and planets shine by reflected sunlight, not by their own light.

e. the appearance, general composition, relative position and size, and motion of objects in the solar system, including planets, planetary satellites, comets, and asteroids.

Reactions

5. Chemical reactions are processes in which atoms are rearranged into different combinations of molecules.

As a basis for understanding this concept, students know:
a. reactant atoms and molecules interact to form products with different chemical properties.
b. the idea of atoms explains the conservation of matter: in chemical reactions the number of atoms stays the same no matter how they are arranged, so their total mass stays the same.
c. chemical reactions usually liberate heat or absorb heat.
d. physical processes include freezing and boiling, in which a material changes form with no chemical reaction.
e. how to determine whether a solution is acidic, basic or neutral.

Chemistry of Living Systems (Life Science)

6. Principles of chemistry underlie the functioning of biological systems.

As a basis for understanding this concept, students know:
a. carbon, because of its ability to combine in many ways with itself and other elements, has a central role in the chemistry of living organisms.
b. living organisms are made of molecules largely consisting of carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur.
c. living organisms have many different kinds of molecules including small ones such as water and salt, and very large ones such as carbohydrates, fats, proteins and DNA.

Periodic Table

7. The organization of the Periodic Table is based on the properties of the elements and reflects the structure of atoms.

As a basis for understanding this concept, students know:
a. how to identify regions corresponding to metals, nonmetals and inert gases.
b. elements are defined by the number of protons in the nucleus, which is called the atomic number. Different isotopes of an element have a different number of neutrons in the nucleus.
c. substances can be classified by their properties, including melting temperature, density, hardness, heat, and electrical conductivity.

Density and Buoyancy

8. All objects experience a buoyant force when immersed in a fluid.

As a basis for understanding this concept, students know:
a. density is mass per unit volume.
b. how to calculate the density of substances (regular and irregular solids, and liquids) from measurements of mass and volume.
c. the buoyant force on an object in a fluid is an upward force equal to the weight of the fluid it has displaced.
d. how to predict whether an object will float or sink.

Investigation and Experimentation

9. Scientific progress is made by asking meaningful questions and conducting careful investigations.

As a basis for understanding this concept, and to address the content the other three strands, students should develop their own questions and perform investigations. Students will:
a. plan and conduct a scientific investigation to test a hypothesis.
b. evaluate the accuracy and reproducibility of data.
c. distinguish between variable and controlled parameters in a test.
d. recognize the slope of the linear graph as the constant in the relationship y=kx and apply this to interpret graphs constructed from data.
e. construct appropriate graphs from data and develop quantitative statements about the relationships between variables.
f. apply simple mathematical relationships to determine one quantity given the other two (including speed = distance/time, density = mass/volume, force = pressure x area, volume=area x height).
g. distinguish between linear and non-linear relationships on a graph of data.