Appendix

Problem Set Answers

Session 1. Earth's Solid Membrane: Soil

1. Make a two-column chart that lists possible components of soil. Label one column "inorganic" and the other column "organic." Make sure to include all the main components of soil. Justify your selections.

Inorganic	**Organic**
Water	Microorganisms
Air	Decaying plant material
Sand and other minerals	Decaying animal material
Silt	
Clay	
Nutrients	

Water comprises 25% of most soils and air comprises another 25%. Sand, silt, and clay are all products of weathered rock, and some combination of each is present in most soils. Microorganisms convert the decaying plant and animal material into organic soil matter called humus. Chemical elements that are products of weathering within the soil are released into the rainwater and utilized by plants as nutrients.

2. Explain the differences between physical and chemical weathering.

Physical weathering involves the physical breakdown of rock into varying sizes of loose material. Physical weathering leaves the chemical composition of the rock unchanged, reducing the rock in size only. There are several processes of physical weathering. Freeze/thaw weathering occurs when the temperature goes through cycles of extreme cold and heat, either daily (like in a desert) or seasonally (like in New England). Water gets trapped in the cracks of rocks and, upon freezing, can expand and fracture the rock, causing the crack to enlarge and rock material to break off. Another type of physical weathering is biological weathering, which occurs when the roots of trees or other plants grow into the cracks in rocks and slowly enlarge the fractures as they grow. Biological weathering can also be caused by burrowing animals, which transport rock fragments and contribute to the disintegration of rocks, and fungi and lichens, which are acid-producing microorganisms that live on rocks and dissolve various nutrients in rock, such as phosphorous. These microorganisms assist in the breakdown and weathering of rock.

Chemical weathering, a change in the chemical composition of rock, occurs as minerals in rocks chemically react with water or other things in the environment. This causes these minerals to undergo chemical changes, or to completely dissolve. Water is an essential agent of chemical weathering and speeds up the weathering of minerals in rocks. The acids present in rainwater start reacting with rock as soon as they come into contact with it. There are several types of chemical weathering which include the following processes:

- **Hydration** simply involves the absorption of water into the existing minerals of the rock, causing the expansion of the mineral and leading to eventual weakening. It is less severe than hydrolysis, the most significant chemical weathering process, whereby H+ and OH ions in water react with the mineral ions.
- **Carbonation** is a result of the reactions between rainwater and carbon dioxide to produce carbonic acid, which slowly dissolves any rocks made of calcium carbonate, such as limestone.
- **Oxidation** occurs upon contact of the rock with oxygen from the air or water. A common effect is the "rusting" of rocks containing iron. The chemical structure of the rock is altered by oxidation, making it more susceptible to other forms of weathering.

Problem Set Answers, cont'd.

3. Write a paragraph explaining why soils are not permanent.

   Soils develop from weathered rock material and organic material. Soils form over a variety of time scales—tens, hundreds, thousands, or tens of thousands of years—depending on the climate in which they form. The hotter and wetter the climate, the faster the soil will develop. However, in the relative blink of an eye, soil can be eroded away by water and wind. In many cases, soils are eroded away faster than they can form. Soils lose their ability to hold water when they are depleted of organic matter. For example, when soils that are used for agricultural purposes are left dry and unfertilized for long periods, they become vulnerable to strong winds, which can transport enormous quantities of soil particles for hundreds and even thousands of miles. Soils can also become damaged through contamination and pollution. Sometime soils are so badly damaged that they cannot be reclaimed through treatment, and have to be removed. Soils can also erode by falling victim to landslides or from humans clearing them away for building and development.

Session 2. Every Rock Tells a Story

1. Explain how a typical sedimentary rock forms in a water environment.

   Most sedimentary rocks form at the bottom of rivers, lakes, and oceans. Sediments—small, weathered pieces of rocks—can be transported by wind, rain, or flowing water before they are deposited in aqueous environments. Sediments carried by water settle on the riverbed, lakebed, or ocean floor due to gravity. Deposited sediment gradually accumulates in horizontal layers; eventually the weight of the overlying sediments compacts the sediments below. This squeezes together the sediment, squeezing out some of the water between the grains of sediment, and forcing them into a tight formation. The water that remains in the pore spaces can react with minerals to cement the sediment grains together.

2. Describe how the size and shape of sediment grains affect their transport and sorting.

   Smaller, lighter sediments (like clay and fine sand) are generally transported farther distances than large, dense sediments (like cobbles and boulders). As sediment is carried in water, it is further weathered from chemical reactions with the water and from abrasion against other sediment and the ground, and it eventually becomes rounded and smooth.

   Sorting describes the range of grain sizes in a collection of sediment. Well-sorted grains of sediment are uniform in size, and are usually associated with calm and/or deep waters. Rough, turbulent water collects a range in sediment sizes, resulting in a poorly-sorted collection of sediment.

3. What evidence do we have for the movement of tectonic plates? Explain how we know that tectonic plates move. Research "global positioning system"(GPS) technology: How does it work? What can we learn about plate tectonics by using GPS technology?

   During the 1950s and 60s, scientists began to understand that the Earth's surface consists of tectonic plates, and that these tectonic plates move relative to one another. They noticed that continents fit together like puzzle pieces; that magnetic lineations on the seafloor were symmetric on either side of spreading ridges; and that hot spot island chains had formed in similar directions on the Pacific plate and other plates.

   By using the global positioning system (GPS), scientists can confirm that tectonic plates move relative to each other, and can determine how far they move each year.

   To date, GPS consists of a network of 24 satellites, each in orbit approximately 20,000 kilometers above the Earth. These satellites send signals to GPS receivers on Earth that enable both the position of the satellite and the distance to the satellite to be determined. GPS receivers accurately indicate positions

Problem Set Answers, cont'd.

on the Earth by measuring the distance to four or more satellites. The satellites broadcast their positions, and the carrier signal of each satellite is modulated by a certain code. GPS receivers compute the travel time by synchronizing with that code. When the receiver code and the satellite code are correlated, the travel time is known. By using the time delays of the signals to calculate the distance to each satellite, the GPS receiver knows where it is relative to the position of the satellites. By repeatedly measuring distances between specific points on the Earth's surface, geologists can track one point's movement on the Earth relative to another point, allowing them to measure things like plate movement and mountain uplift.

Session 3. Journey to the Earth's Interior

1. Consider the following statement: "The rock that makes up the Earth's mantle flows." Do you agree or disagree? Explain the reasons for your answer.

   The mantle is the thickest layer of the Earth, lying below the crust and above the core. It is composed of very hot, dense, and slowly moving rock. The rock of the mantle behaves as a flowing solid. Although the rock of the mantle is solid, the heat and pressure inside of the Earth are great enough to deform the rock. The mantle flows because of convection currents that are created when hot, buoyant material rises, and then cools, becomes dense, and sinks again.

2. Identify the type of igneous rock that is most common and explain its origin.

   Basalt is the most common type of igneous rock, and the most common type of rock in the Earth's oceanic crust. Basaltic magma is commonly formed by the partial melting of the upper mantle. When the mantle melts, basaltic magma wells up at mid-ocean ridges and builds new ocean floor. Basaltic magma covers about 2/3 of the Earth's surface. Basaltic lava also erupts from hotspot volcanoes, shield volcanoes, some stratovolcanoes, and fissure eruptions. Basalt also erupts in continental rift valleys. It makes up 90% of the bedrock of Iceland because on that island, the mid-Atlantic ridge is at the Earth's surface.

3. How do we know about the nature of Earth's exterior (i.e., tectonic plates)? How do we know about the nature of its interior (i.e., structural layers)?

   Observations about how continents fit together, about the magnetic lineations on the seafloor, and about seafloor spreading in general have given geologists a lot of information about the nature of tectonic plates. Subduction zones, transform faults, spreading ridges, and mountain ranges continually give us clues about the nature of tectonic plates, and GPS helps us quantify their movement.

   We know about the nature of Earth's interior by studying volcanic eruptions, sections of the deep earth that have been uplifted, and especially seismic waves. Seismologists have observed that the velocities of seismic waves change abruptly at certain depths beneath the surface. This allowed them to determine the dimensions of the Earth's layers.

   Compressional waves (also called primary waves, or P waves) and shear waves (also called secondary waves, or S waves) move at different speeds through the different layers. The waves' speeds through the crust are much slower than through the mantle. This tells geologists that the crust must be made of a less dense material than the mantle. The study of seismic waves also revealed the nature of the lower mantle, liquid outer core (through which S waves don't travel), and solid, extremely dense inner core.

Problem Set Answers, cont'd.

Session 4. The Engine that Drives the Earth

1. The oldest oceanic crust is about 200 million years old. The average age of continental crust is about 2 billion years old. Why is this? What does this tell us about the differences between plates topped by continental crust and plates topped by oceanic crust? How do the two types of plates interact?

   Oceanic crust is usually much younger than continental crust. This is because oceanic crust is continuously generated at spreading ridges and recycled at subduction zones. At many plate margins, oceanic crust is subducted under continental crust (or other oceanic crust). Continental crust is usually not recycled because it is less dense and more buoyant than either oceanic crust or the mantle. As a result, it resists subduction. During continent-ocean as well as continent-continent collisions, buoyant melts are generated and felsic rocks are created, thickening the continental plates and ensuring their survival for longer than most oceanic plates.

2. Early in the video for Session 4, two types of volcanoes are compared. Scientists actually recognize several kinds of volcanoes. Research the different types of volcanoes and create a chart that outlines their general characteristics and differences.

Cinder Cones	**Shield**	**Stratovolcanoes**	**Volcanic Domes**
Steep slopes	Shallow slopes	Steep slopes	Steep, rounded mounds
Eruptions with high gas content and low silica content	Eruptions with low gas content and low silica content	Eruptions with high gas content and high silica content	Eruptions with low gas content and high silica content
Composed of fragmented lava called cinders and bombs	Composed of highly fluid lava flows	Composed of alternating layers of lava, volcanic ash, and cinders and bombs	Composed of one or more lava flows
Commonly found on the flanks of stratovolcanoes, and some shield volcanoes	Found at hotspots and some volcanic arcs	Commonly found along subduction-related volcanic arcs	Commonly occur within the craters of stratovolcanoes

3. In the video, Dr. Dave Sherrod suggests that Earth's internal heat contributes to plate movement by generating convection currents. A convection current can be described as a current of hot, buoyant material that rises up through the mantle, cools, becomes dense and sinks back down. Other scientists suggest a more physical "push-pull" tectonic plate model, where subducting slabs pull plates down and spreading ridges push plates apart in a manner analogous to a conveyor belt. Could both of these ideas be accurate? Explain your answer.

   The most basic reason behind plate movement is the high temperature inside of the Earth. It was first thought that convection currents in the mantle were the main cause of plate movement. Variations in the density of rock in the mantle produces convection currents. In these currents, cooler, more dense rock material moves downward and warmer, less dense rock material moves upward. This continuous cycle is called a convection cell. Convection cells occur when material is heated from below and cooled from above, like soup heated on a stove.

   There are, however, other important forces at work that cause plate movement. At divergent plate boundaries (called spreading ridges), two oceanic plates move apart. As they move apart, molten mantle material rises to the surface and cools, to form new oceanic crust. The elevation of the surface of the oceanic crust is higher at the ridge than at the adjacent sea floor because the rock material under the ridge is hot asthenospheric material, and erupted lavas can pile up at the ridge. As the surface of the sea floor slopes away from the ridge, gravity causes the elevated lithosphere to push against the rest of the seafloor, which spreads the plates apart. This is called the ridge-push force.

Although ridge-push may play a role in plate spreading, scientists think a more important force is at work driving plate tectonics at subduction zones. When a plate subducts and sinks into the mantle, the force of that dense plate being pulled deeper and deeper into the earth's interior is very strong, and pulls the rest of the plate behind it. This force is called slab-pull.

The forces of slab-pull and ridge-push set up is essentially a conveyor belt in which rock is created at spreading ridges, towed across the sea floor, and subducted back into the Earth at convergent boundaries.

Convection currents work in conjunction with the forces of slab-pull and ridge-push to move tectonic plates. The convection currents move heat from the Earth's interior to the upper mantle, where it promotes melting and magma generation at spreading ridges and other volcanic centers.

Session 5. When Continents Collide

1. Is it possible for more than one type of mountain-building event to occur at a single convergent plate boundary? For this session, you created two models. One portrayed a collision between a plate carrying oceanic crust and a plate carrying continental crust, and the other portrayed a collision between two plates carrying continental crust. Use what you understand about plate tectonics to construct a scenario where one collision is followed by the other. What are the possibilities that this has happened during Earth's history? What geological evidence would you look for?

   Consider the following scenario. Two plates share a convergent boundary. One is a plate with only continental crust. The other plate has a leading edge of oceanic crust, but farther away carries continental crust. The oceanic crust is subducted under the continental crust at the convergent boundary. When the oceanic plate subducts under the continental plate, it brings water with it, which can induce melting in the mantle. This resulting magma rises and can lead to volcanism inland from the convergent boundary.

   The plate continues to subduct. Eventually the buoyant continental lithosphere carried by this plate will come to the convergent boundary. This continent usually cannot be subducted. The two continents collide. Although some material during the collision is pushed down into the mantle, neither continent is subducted because continental rock is not very dense, and therefore resists sinking. Instead, the rocks rise up, folding and thrusting into mountains.

   A good example of this sequence of events is found in the history of the Himalayas, where an oceanic plate was subducted beneath Eurasia until the Indian continent arrived at the convergent margin and began the mountain building that continues today.

Problem Set Answers, cont'd.

2. One of the rocks that Dr. Klepeis investigated at Clay Point in Vermont was a metamorphic rock. Make a chart comparing the characteristics of sedimentary, igneous, and metamorphic rocks and the processes that form them. Be sure to bring this chart to the next session.

Sedimentary Rocks	Igneous Rocks	Metamorphic Rocks
Form from mineral and rock fragments (and sometimes organic material) that is eroded then re-deposited	Form from the crystallization of magma	Form when any type of rock (sedimentary, igneous or another metamorphic rock) physically or chemically changes while subjected to high temperatures and/or pressures, or by reaction with chemical solutions
Form at the Earth's surface	Form at the surface (volcanic/extrusive) or inside the Earth (plutonic/intrusive)	Form inside or near the surface of the Earth
During formation, clastic and organic sedimentary rocks remain solid, and chemical sedimentary rocks precipitate out of solution as a solid	During formation, begin as magma and solidify as they cool	Usually remain solid throughout the processes of formation

3. At this point in the course, we have discussed the three main types of rocks found on Earth. Over immense time scales, rock can change from one type to another. The "engine" of plate tectonics can be envisioned as a giant conveyor belt that recycles Earth's materials as the matter that makes up rocks is redistributed and transformed from one rock type to another. The relationship between igneous, sedimentary, and metamorphic rocks is known as the rock cycle. Using only course materials, make a diagram that represents how you think this cycle works. After creating your diagram, consult another resource (e.g., your college-level textbook or the Web) and study how the rock cycle is depicted. Create a second diagram that integrates any new information from the resource that you used. Write a few sentences explaining the processes represented in your final diagram.

   Magma solidifies either at the Earth's surface or inside of the Earth to form igneous rock. The exposure of igneous rocks to weathering and erosion on the surface breaks them down into small grains called sediments. The grains of sediment are transported by wind, water, and ice and are eventually re-deposited in horizontal layers before being compacted and cemented to form sedimentary rocks. Subjecting those rocks to high temperature, pressure, and/or changing their chemical constituents can cause changes in igneous and sedimentary rocks to form metamorphic rocks. When exposed to higher temperatures, any rock type may be melted, resulting in the creation, once again, of igneous rocks and starting the cycle all over again.

Problem Set Answers, cont'd.

Session 6. Restless Landscapes

1. Describe several natural agents responsible for sculpting the Earth's surface, and give examples of how each affects the land.

   Running water is the main agent of erosion on the Earth's surface. Running water cuts channels into the Earth's surface and can remove loose fragments of sediment. Water can also break chunks of rock free from a stream or river floor or bank and transport them. Sometimes water can push open and enlarge cracks in surface rock. Sand-laden rivers and streams grind away (or abrade) rock in the water channels. Water can also dissolve soluble minerals and create sinkholes and caves. Coastal erosion caused by ocean waves can transport large quantities of sand and abrade rock cliffs, while flooding rivers can strip land of soils and loose rocks.

   Erosion by wind is called eolian erosion, and occurs mostly in deserts. Winds carrying sand can abrade rock, sculpting landforms such as arches. Sand dunes are also formed by wind.

   Glaciers also cause significant erosion. Glaciers can pick up rocks, trees, and other materials of all sizes as the ice carves the land. Glaciers that travel through valley walls make the valleys wider and deeper. Glaciers leave grooves, gouges, and scratches on the landscape called glacial striations, and when they recede they deposit enormous amounts of sediment in moraines, eskers, and outwash streams.

2. Describe the different types of glaciers. In what ways are glaciers like streams? In what ways are they different?

   There are two main types of glaciers: valley glaciers and continental glaciers. Valley glaciers are found in high mountain valleys, and move like slow, frozen rivers in that they carry sediment along valleys and re-deposit it elsewhere. While rivers are fast-moving and full of living things, valley glaciers move very slowly, are fed from high points of snowfall, and do not usually support much life.

   Ice sheets, ice caps, and ice fields are types of continental glaciers. Each type is extremely broad, and spreads laterally over enormous expanses of land, unlike valley glaciers, which are usually confined to mountain valleys.

Problem Set Answers, cont'd.

Session 7. Our Nearest Neighbor: The Moon

1. What evidence suggests that the Moon formed with a molten surface?

   The material that forms the white, light-colored highlands of the Moon is made of a type of rock called anorthosite. Anorthosite is an igneous rock that is formed from magma. While rare on the Earth, this type of rock is widespread on the Moon, which means that the entire surface of the Moon must have once been magma. As the magma "ocean" cooled off, anorthosite accumulated at the surface and solidified. John Wood theorized this explanation in 1970.

   The magma ocean is predicted by the giant impact hypothesis for the creation of the Moon. The energy released in the impact that created the Moon along with the heat created from the continual bombardment of the young Moon were enough to keep its surface in molten form. Neither the co-formation hypothesis nor the capture model predicts that the surface of the Moon should have once been molten.

2. What can the cratering on the Moon tell us about the Earth and events in Earth's early history?

   The cratering on the Moon is relevant to Earth's early history because the Moon is nearly the same age as the Earth, and has existed alongside Earth since its creation. Because of this, it is safe to assume that the same types of objects that impacted the Moon also impacted Earth, and with about the same frequency. Evidence of the Earth's early history has been lost to erosion and tectonic plate movement, but the Moon's surface has not been affected by either process, and is therefore a window to our past.

   The size of a crater is determined by the sizes of the objects colliding with the Moon. By counting the number of small craters inside the largest impact basins, it is possible to determine the rate at which impacts of differing sizes occurred. From studies of the Moon, we can tell that Earth must have passed through a period of intense bombardment followed by a slowing rate of meteorite impacts.

3. How does the Earth's Moon compare with other moons in the Solar System? Research this beyond the information provided in this session's video. Create at least four statements of generalization that describe the nature of the moons in our Solar System, particularly in comparison to our Moon.

   Earth's Moon is much more massive than most of the moons in the Solar System. Only the moons Io, Ganymede, and Callisto of Jupiter and Titan of Saturn are larger. The Moon is more massive than the planet Pluto.

   The Moon is much bigger relative to the Earth than most other satellites are relative to their host planets. The Moon is just over 1% of the Earth's mass whereas Jupiter's largest moon, Ganymede, is less than 0.01% of Jupiter's mass, and the mass of Mars' moon, Phobos, is 0.000001% the mass of Mars. The only planet-moon system where the moon is closer in mass to its planet than the Moon is to the Earth is that of Pluto and Charon. Charon is 14% as massive as Pluto.

   Earth's Moon, like most other moons in the solar system, has no atmosphere. Saturn's moon Titan has an atmosphere thicker than Earth's, and the largest moons orbiting the gas giants also have atmospheres, but they are very thin. The smaller moons all lack an atmosphere.

   Earth's Moon orbits in the same direction that the Earth rotates (a prograde orbit). This is true for most of the moons in the solar system, including the moons of Mars and largest moons of Jupiter and Saturn. There are, however, moons with retrograde orbits, including Triton, a moon of Neptune. Saturn's moon Phoebe also orbits in a retrograde direction, as do many of the minor moons of Jupiter. Scientists believe that moons with retrograde orbits were captured by their host planets.

Action Research Guide

The Action Research Process

Identify your starting point for research

Refine your thinking

Formulate a research question

Develop and implement strategies for action

Collect and analyze data

Reflect on action

Generate practical knowledge

One of the primary reasons for doing action research is to generate knowledge that can inform classroom practice. Your research for the *Earth and Space Science* course should focus on some aspect of science teaching and learning in your classroom. Issues involving content, pedagogy, assessment, management, or using children's ideas are all possibilities for productive research. The following is an outline of stages of action research tailored for a 15-week graduate-level course. Refer to the list of readings related to action research that follows for more information.

Weeks 1–3: Identify Your Starting Point

Begin your action research by reflecting on your current practice and identifying an area of special interest to you. Ask yourself these questions to organize your thinking:

- What science content presents problems for my students?
- Which pedagogical approaches help or hinder me in addressing children's science ideas?
- How do I use assessment to guide my science teaching?
- Which educational situations make teaching science content difficult for me?
- What strengths related to addressing children's ideas would I like to develop?

Gather preliminary data through classroom observations and note taking. Your notes should include detailed descriptions and interpretations, explanatory comments, summaries of conversations, hunches, and insights. Reflect on your role within your area of interest to help you think about alternative courses of action.

Think about your current situation and one that would represent improvement. This can help you understand the sources of problems that your action research will address.

Action Research Guide, cont'd.

Weeks 4–5: Refine Your Thinking

Phrase a preliminary research question that has emerged from a review of your notes. Think about what possible action you could take to better understand this question as well as aspects of your classroom practice you could change to better address issues raised by your question. Collect additional information and reflect on how this knowledge will impact your research question. Revisit and adjust the research question you phrased earlier to reflect any changes in thinking.

Week 6: Formulate a Research Question

Reconstruct your research question into a question with two variables in mind—a strategy and an outcome—to help you be more specific about your research and to make it more focused and manageable.

Week 7: Develop Strategies for Action

Identify several possible strategies for action ranging from radical changes in pedagogy to slight behavior modifications. Determine what kinds of data to collect that are appropriate to your question.

Week 8: Implement Strategies for Action and Begin Collecting Data

Begin to implement your chosen strategy and collect the appropriate data.

Weeks 9–12: Refine Action, Continue Data Collection, and Begin Data Analysis

Begin to interpret and draw conclusions from your data about the success of your strategy for action. Writing data summaries after reviewing sections of your data is an effective method for organizing and informing your analysis. Check the validity of your perceptions of your progress by establishing a consensus view of the results. You might interview students, ask a neutral party to observe your class, or choose a colleague to be a "critical friend." Consider the reliability of the data you are collecting. If you come across data that substantiates an important finding for your research, search the rest of the data for conflicting evidence that could refute the finding. It is important that you are open to data that both questions and supports your hypothesis.

Begin a theoretical analysis to take your data analysis to another level. After reviewing a section of your data, try writing a summary in which you identify and interpret themes, contradictions, relationships, and different perspectives that are represented in the data. Developing these ideas can lead to establishing practical theories about teaching.

Week 13: Conclude Strategy Implementation and Continue Data Analysis

Draw the implementation of your chosen strategy to a close. Begin to organize information about your methods of data collection and analysis and bring your interpretations of the meaning of your data to some kind of conclusion.

Week 14: Generate Practical Knowledge

Draw conclusions from the activity of your research. Begin to work on organizing a research report that should minimally include an introduction that explains the context of the research and the research question, a description of methods of data collection and data analysis, results of the data analysis, conclusions you have drawn from the study, and the implications of your findings for your teaching.

Week 15: Generate Practical Knowledge

Complete the research report.

Action Research Guide, cont'd.

Readings on Action Research

The following resources will provide you with additional guidance to conduct your action research project:

Altrichter, H., Posh, P., and Somekh, B. (1993). *Teachers Investigate Their Work: An Introduction to Methods of Action Research.* NY: Routledge.

Hubbard, R. and Power, B. (1993). *The Art of Classroom Inquiry.* Portsmouth, NH: Heinemann.

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Bogdan, R. and Biklen, S. (1998). *Qualitative Research in Education. An Introduction to Theory and Methods.* Third Edition. Needham Heights, MA: Allyn & Bacon.

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McNiff, J. (2003). "Action Research in the Classroom: Notes for a Seminar." Available at http://www.leeds.ac.uk.educol/documents/00002397.htm.

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Related Readings List

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Lillo, J. (1994). An analysis of annotated drawings of the internal structure of the earth made by students aged 10-15 from primary and secondary schools in Spain. *Teaching Earth Sciences,* 19, 83-87.

Marques, L. and Thompson, D. (1997). Portuguese students' understanding at ages 10 and 11 and 14-15 of the origin and nature of the Earth and the development of life. *Research in Science and Technological Education,* 15(1), 20-51.

Osborne, J., Wadsworth, P., Black, P., and Meadows, J. (1994). Primary SPACE Project Research Report: The Earth in Space. Liverpool, UK: Liverpool University Press.

Oversby, J. (1996). Knowledge of Earth science and the potential for its development. *School Science Review,* 78(283), 91-97.

Phillips, W. (1991). Earth science misconceptions. *Science Teacher,* 58(2), 21-23.

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Course Readings

Concept Mapping as a Study Strategy in Earth Science

Concept mapping leads students away from rote learning and toward true understanding of concepts and their relationships.

Charles R. Ault, Jr.

Concepts signify patterns in events and connect experiences that are otherwise unrelated.

Educators who expect "meaningful learning" from their students are often disappointed. Students who fail to learn "meaningfully" gain little knowledge of lasting importance from a course. Is the hope that our students will become flexible, critical thinkers at some worthwhile level of insight an impossible, even foolish, fancy?

Novak has aptly phrased the question that too frequently haunts educators: "Why do so many students learn so little?" [14,p.9].

Having rejected simplistic explanations that students "don't try to learn" and teachers "don't care about teaching," Novak invented a procedure for helping students to organize concepts into meaningful—as opposed to loosely connected—entities. He called this procedure concept mapping.

The tactic holds promise for many phases of science instruction and study [10]. A concept map depicts hierarchy and relationships among concepts. It demands clarity of meaning and integration of details. Mapping exercises require one to think in multiple directions and to switch back and forth between different levels of abstraction.

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Concepts

Concepts signify patterns in events and connect experiences that are otherwise unrelated. Consider, for example, how some elementary concepts of wave energy connect two seemingly unrelated events: silent flashes of "heat lightening" from a distant thunderstorm observed on the horizon and "heat rising" on a cold day over a steam-filled radiator just beneath a window. In both instances, variations in air density alter the paths of wave energy propagation. Sound waves refract upward into the atmosphere, their speed being greater in the lower, denser air and slower above. Normal thunder exists, but misses a surface observer a "horizon distance" away [22].

Over the radiator, cold and hot air mix in a turbulent plume. This region of intense convection shimmers while transmitting light. Density variations in the air cause numerous refractions and reflections of the light. We perceive light coming from so many directions at once as "shimmers." Objects viewed through the "rising heat" are distorted.

Explanation in terms of "wave-bending" and "wave-reflecting" also connects desert mirages, shimmering "puddles" in dips on hot, dry pavement, clear voices overheard through a doorway when the door is but slightly ajar, the shapes of clouds, the distortions of olive sizes in a tall, slim, round, glass jar—the list is, of course, endless.

No single concept could make these connections intelligible. Concepts do not exist in isolation. Each concept depends upon its relationships to many others for meaning. In the wave energy example, density becomes understood partly as a property of matter capable of influencing wave speed.

Meaningful Learning

A personal grasp of such relationships characterizes "meaningful learning" as defined by Ausubel [3-5]. Concept mapping—with its emphasis on integrating concepts and anchoring them to concepts in events and objects—is one tool for enhancing meaningful learning.

Isolated terms, remembered precisely as learned and unconnected to a student's own imagery (olive jars and thunderstorms), make up the other end of Ausubel's learning continuum. Rote learning often defeats students with a burden of memorization without purpose, a strain from acquiring information without structure, and a frustrating emphasis on reproducing information exactly as presented.

Some students tend to see science learning as a necessary but senseless chore. Current trends in science education focus on means of helping them to overcome their rote learning handicaps. Arons has noted the failure of introductory physics students to assimilate a clear description of physics ideas relevant to solving a particular problem, even when these ideas are readily available in texts and clearly presented in lectures. He claims it is essential to "train the students to a fixed habit of asking themselves for a restatement of the meaning of every term they encounter in a problem which gives them

A concept map depicts hierarchy and relationships among concepts. It demands clarity of meaning and integration of details. Mapping exercises require one to think in multiple directions and to switch back and forth between different levels of abstraction.

Sea-Floor Spreading—Another Outrageous Hypothesis

It was submarine extension or ocean spread constantly in progress . . . Asia was therefore formed not by overthrusting, but by underthrusting. (Bailey Willis, 1907).

Recall that, in 1928, Scottish geologist Arthur Holmes presented a hypothesis of convection in the mantle as a cause of mountain building, and in the same year, Alfred Wegener also accepted convection as one possible mechanism for continental drift. Since that time, convection has been the most widely endorsed mechanism to explain large-scale tectonic features. In 1962, Princeton University geologist H.H. Hess proposed a bold new hypothesis that two opposing thermal convection cells rising beneath ocean ridges produce tension in the crust and also cause the abnormal heat flow observed there. As rifting occurs, earthquakes are generated beneath ridges, and new crustal material is erupted volcanically at ridge axes. Hess envisioned that, finally, the slow, convective flow laterally away from ridge axes carries older oceanic crust along as if on a conveyor belt, causing the spreading of sea floors through time. Original as Hess's idea was, it appears from the above quotation that he had been partially anticipated 55 years earlier.

Figure 1. A passage from a college introductory geology textbook [7] selected for concept mapping.

Focus: "Tectonic Features"
Most Inclusive Concepts:
- convection
- large scale
- lateral flow
- thermal cells

Highly Abstract Concepts:
- tension
- heat flow

Abstract/Concrete Concepts:
- rifting
- ridge axes

Concrete Level:
- ocean ridges
- volcanic eruptions
- crustal material
- sea floor
- continents

Figure 2. Concept map preparation steps 2 and 3—rank and cluster concepts.

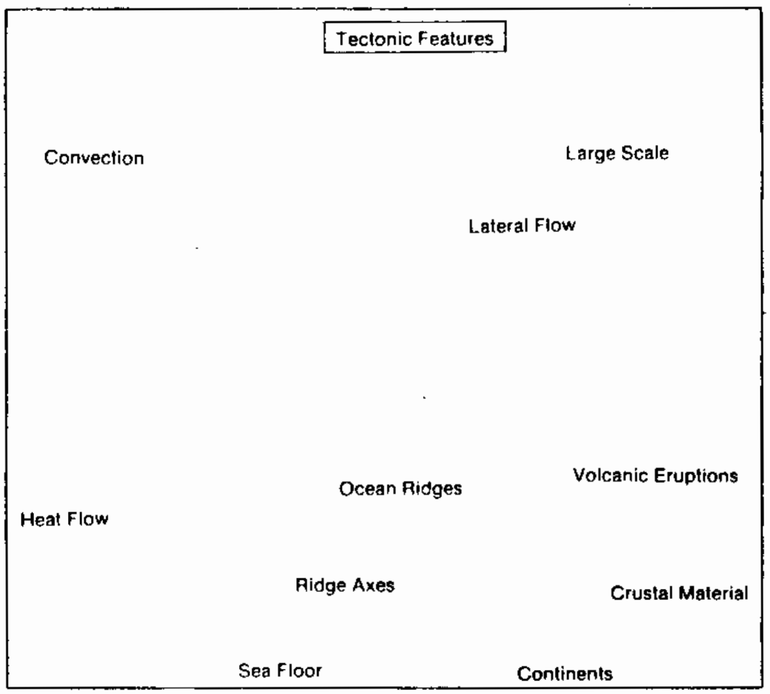

Figure 3. Concept map preparation steps 3 and 4—cluster and arrange concepts.

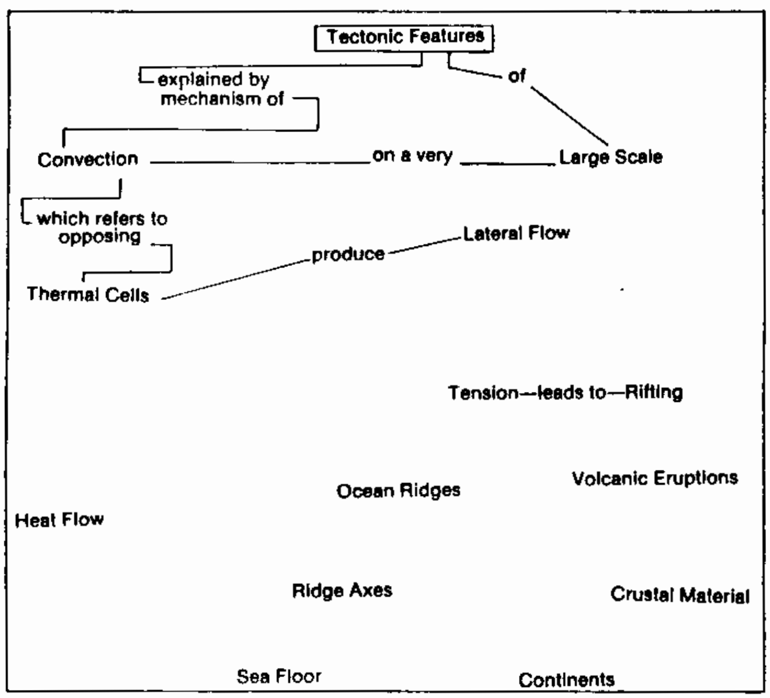

Figure 4. Concept map preparation step 5—link and label relationships among concepts.

difficulty" [2,p.172]. Even language becomes important in these restatements. For example, students may say a ball tossed into the air "has zero velocity for a moment" upon reaching the apex of its flight, instead of "has zero velocity at the moment" it reaches the apex. Aron's work clearly indicates how misconceptions can create problem-solving difficulties.

McCloskey [11] calls these misconceptions "intuitive physics." He holds the view that clear statement of personal beliefs and meanings, rigorous analysis of their consequences, and comparison of personal understanding to expert versions of the same concepts promises improved understanding. Kahle, Lehman, and Carter [9]; Novak [15, 17]; and Novak, Gowin and Johansen [18] have concluded that learning should be more meaningful if students "map" key concepts in network forms revealing hierarchy and relationships.

Concept Mapping

In contrast to rote learning methods, concept mapping permits variation in right answers. There are many possible patterns capable of connecting concepts. Maps permit comparison of student understanding with expert knowledge. They improve understanding by searching personal meanings for misconceptions or incorrect relationships among concepts. They also illuminate insights into meanings of elementary concepts ("density alters wave propagation" as opposed to "density is mass per unit volume").

Recent studies on meaningful learning and concept mapping have focused primarily on learning biological concepts [9,12,15-19]. Stewart [20] has attempted to adapt the techniques to the field of genetics.

Several forms of network diagrams—or flowcharts representing knowledge and text structure—have emerged during recent years. Such techniques are firmly grounded in cognitive psychology [1,13] and reading instruction [8].

The following directions and examples are patterned on the Novak tradition of techniques designed for student use.

Concept Map Preparation

Directions for constructing concept maps are simple. Executing the directions is not. The technique must be attempted to be understood. Patience for mapping requires a purpose for the map—a need to truly understand a set of concepts.

Concepts do not exist in isolation. Each concept depends on its relationships to many others for meaning.

The "raw material" for mapping may come from a text, lecture notes, personal knowledge, or any other source. The following example uses a passage from a historical geology textbook [7]. The division of the mapping process into five steps—select, rank, cluster, arrange, link—is somewhat arbitrary but helpful as an introduction.

Step 1: Select an item for mapping (See Figure 1). The item may be an important text passage, lecture notes, or laboratory background material. Use short passages for initial mapping attempts. After reading the passage at least once, determine a central or focus concept. Ideally, this focus concept will identify the role of the mapped passage in some larger context (the entire chapter, for example).

Next, choose and underline key words and phrases; include objects and events. Copy each of these concepts onto a separate small card for easy rearrangement.

Step 2: Rank the list of concepts from the most abstract and inclusive to the most concrete and specific. There are no fixed rules for establishing this ranking. It satisfies a need to find hierarchical structure in the material. If the selection contains many concrete examples but very few abstractions, select another passage. Several concepts may share the same level of abstraction; generally, you will find fewer abstract concepts than concrete ones (See Figure 2).

Step 3: Cluster the concepts according to two criteria: concepts that function at a similar level of abstraction and concepts that interrelate closely (each defined in terms of the others, for instance). These groupings reflect judgments about closeness of association and will be expressed in part by concept positions on the final map. To regroup, just rearrange the cards. Discussion helps to clarify these judgments.

Step 4: Arrange the concept cards as a two-dimensional array analogous to a roadmap. Each concept is, in effect, a potential destination for understanding. Its route is defined by other concepts in the neighboring territory. No precisely correct arrangement is possible. There will be frequent revisions as meanings come in focus (See Figure 3). This stage may require returning to the selected passage for additional concepts, reclustering the ranked concepts, reassigning the abstraction level of a concept, or even replacing the focus concept.

Step 5: Link related concepts with lines and label each line in propositional or prepositional form (See Figures 4 and 5). Work with one pair of concepts at a time. Once linkages are labeled, the map becomes "a paragraph that reads in any direction" (in the words of one enthusiastic student). Lines and labels should both branch from concepts and cross levels of abstraction as necessary. Horizontal relationships in many instances will lead to the formation of closed cells. Remember, the analogy is with a roadmap, not a dichotomously branching key. There are many roads from Cleveland to Cincinnati.

A completed map represents an understanding of the relationships entailed by an important set of concepts and efficiently communicates this understanding to others. Map documents set

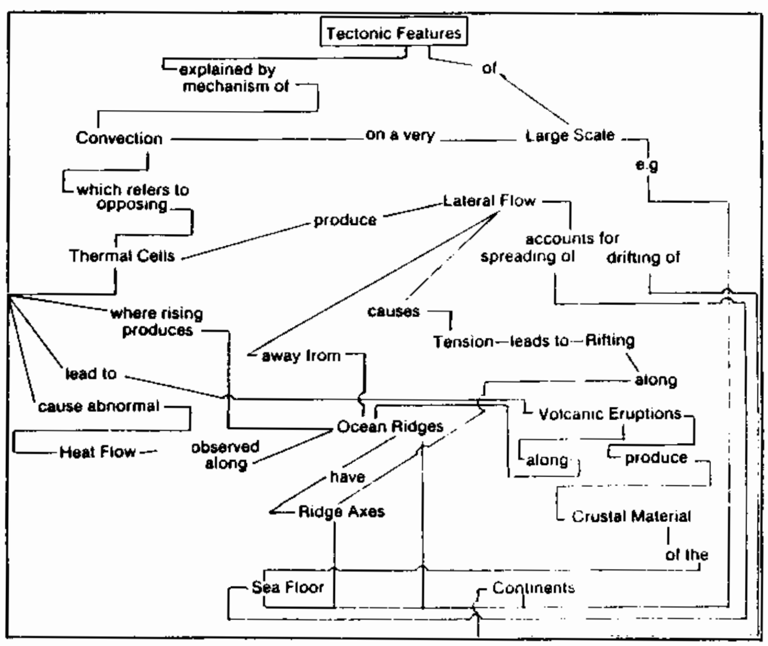

Figure 5. Completed map for the sample text passage introducing sea floor spreading.

the stage for efforts to contrast personal meanings with higher levels of understanding. A map is a piece of private thought made public, ready for revision, review, or perhaps repair.

Work at this stage may require revision of some of the previous steps. The mapping process is a form of self-administered Socratic dialogue, prompting critical appraisal of what one claims to know. No map is ever completely finished. Figure 5 shows the most recent edition of the "Tectonic Features" map.

Only mapping practice brings mapping proficiency. These directions are guidelines, not rules. Wrestle with a mapping task in order to understand, and perhaps change, the directions.

Applications

Constructing, revising, and studying concept maps helps to clarify unfamiliar ideas. The comparison of different individuals' concept maps as a classroom activity or the contrast between maps drawn by the same person over time reveals how prior knowledge interacts with new information.

Mapping benefits instructors, too. Much lecture planning is concept mapping in disguise. Curriculum planning and textbook evaluation require critical thinking about schemes for organizing concepts.

While mapping is no panacea, there are no restrictions on its use, either. The following applications are suggested for science instructors, students, educational researchers, and teacher educators:

- Lecture preparation. Use a concept map to plan a lecture or to integrate several lectures. Distribute a simplified version to the class as lecture notes. Have a colleague attend your lecture and make a map of it for comparison and feedback!
- Curriculum planning and evaluation. Apply mapping to several levels of the curriculum—program, course, book, chapter, topic—to ensure that an organization exists for students to grasp.
- Discussion. Precede, accompany, or follow concept mapping exercises with discussion. Assign partners to construct maps jointly. Have a discussion session to construct a master map of the week's topic.
- Laboratory reports. Have students construct maps of background information prior to lab exercises. Link concepts to lab procedures. Make concept maps of experimental conclusions and then synthesize these maps into the prelab background map.
- Text study. Have students map various size units of text. Direct them to the most essential passages. Have students map their lecture notes, too.
- Examination. Replace some essay assignments with map exercises. Present a set of concepts; ask students to select a focus and construct a map. ("Below are seven concepts associated with precipitation. Use them to construct a concept map.") Directions, source material, and expectations will vary according to teaching style. Try not to ask students to recall concepts or labels from a memorized map.
- Computer Assisted Instruction (CAI). Use concept mapping as an aid to transforming a body of knowledge into a programmable structure. Build a screen page around each concept and determine conditions for calling pages from linkages.
- Knowledge representation. Try (just for fun) to map the patterns of meaning governing expert thinking in a narrow domain.
- Interview analysis. Represent student conceptions with concept maps. Use maps to diagnose misconceptions. Have education majors construct maps of children's conceptions.
- Lesson plans. Have elementary educators use a concept map to represent their understanding of the background knowledge for an elementary science lesson.

Concept mapping is one strategy for solving the problem of why students often learn so little. Judiciously used by either instructors planning lectures or students preparing for an examination, concept mapping enhances opportunities for meaningful learning.

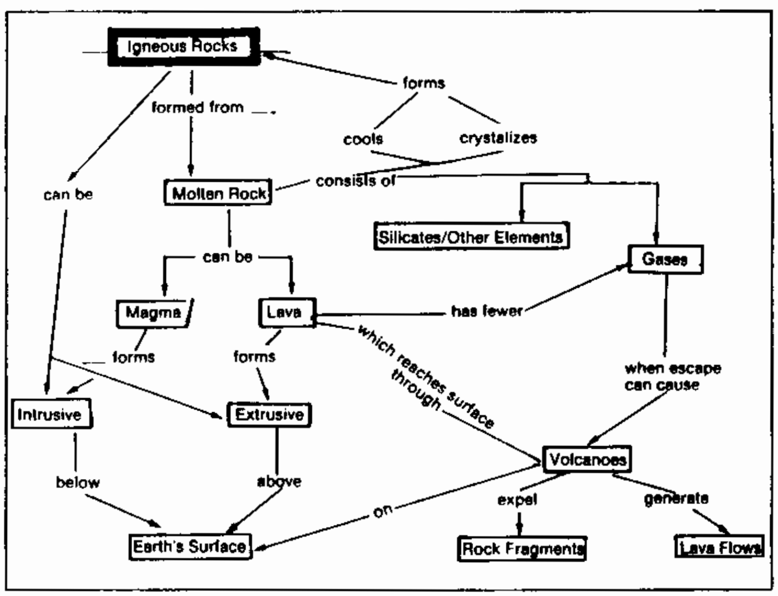

Figure 6. A student-constructed map on "Igneous Rocks" with important links to magma composition.

Other references can provide details on techniques for scoring concept maps quantitatively [10,17]. I believe a map document stands alone, with little need for numerical rating. Subsequent examples illustrate this point.

Sample Maps

Figures 6–9 depict maps drawn by students in introductory geology and earth science courses for nonmajors. Each map has distinctive features worthy of comment. The student map examples cover text passages from one to several paragraphs in length.

The Igneous Rock Map (Figure 6) represents a very well organized, beginning-level understanding of broad igneous rock categories and their relationship to a molten state. The student has noted the significance of gas content to volcanic events. The region of the map entered with the phrase "consists of" has the potential to anchor additional information on magma composition and eruptive events.

The Fossil Map (Figure 7) stresses category/subcategory thinking. Connecting phrases in this map follow conventions developed by Champagne and Klopfer [6]. Linkages state either class membership or change processes. The content of this map stands alone as an introductory-level overview of fossil preservation, but also provides a framework for elaboration of preservation processes and products.

The Precipitation Map (Figure 8) has three explanatory levels. First it accounts for condensation. Next the map focuses on cloud droplet origin. Lastly, by using cloud droplet concepts in a causal sequence, the map attempts to explain raindrops. This map is not a complete explanation of precipitation, but it is an orderly beginning. All the information present interconnects. Incomplete yet informative regions of this map raise questions for future study: What events determine the form in which condensation occurs? Why does droplet size influence coalescence? What keeps light-weight raindrops from falling? This map enables its author to understand a wide range of interesting questions.

The Celestial Equator Map (Figure 9) departs from traditional presentation of these concepts. Usually, the student studies a text illustration of the earth in orbit or the sun at different locations in the sky throughout the year. The symmetry of this map maintains the feel of orbital motion. However, the verbal/propositional form of the map draws attention to essential meanings of ecliptic concepts—meanings often subtle or unrecognized by students. This student has represented the solstices and equinoxes as both calendar dates and positions in the sky, and recognized the basis for these observations as dependent upon a reference system.

Caution and Conclusion

Mapping may be most useful in the context of attempting to grasp difficult new abstractions. However, maps heighten awareness of a need to know more. In nonsupportive settings, in situations where the expected learning is primarily rote, in cases where the difficulty of the new abstractions simply overwhelms the student, or in situations where most students have learned to succeed with rote learning habits, tolerance for mapping exercises will fade rapidly. Students may not want to know more.

Grading practices can thoroughly undermine the value of concept mapping by reinforcing rote learning. Never ask students to memorize instructor-prepared maps.

Scientists feel comfortable working within intricate, highly interconnected systems of thought. Students often do not. Information presented in introductory courses may seem unconnected

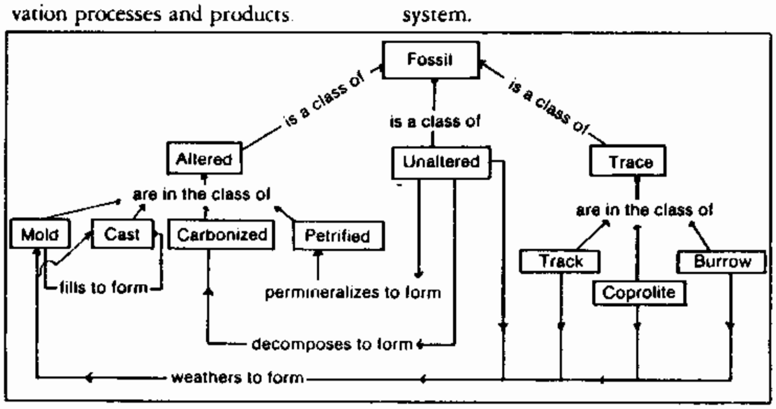

Figure 7. A student-constructed map on "Fossils" emphasizing categorization and change processes.

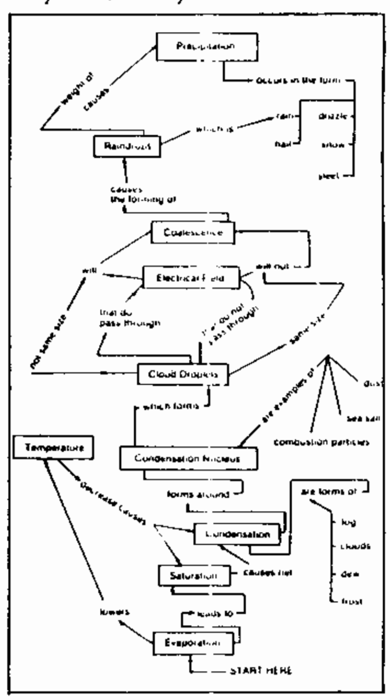

Figure 8. A student-constructed map on "Precipitation" explaining raindrops while suggesting answered questions.

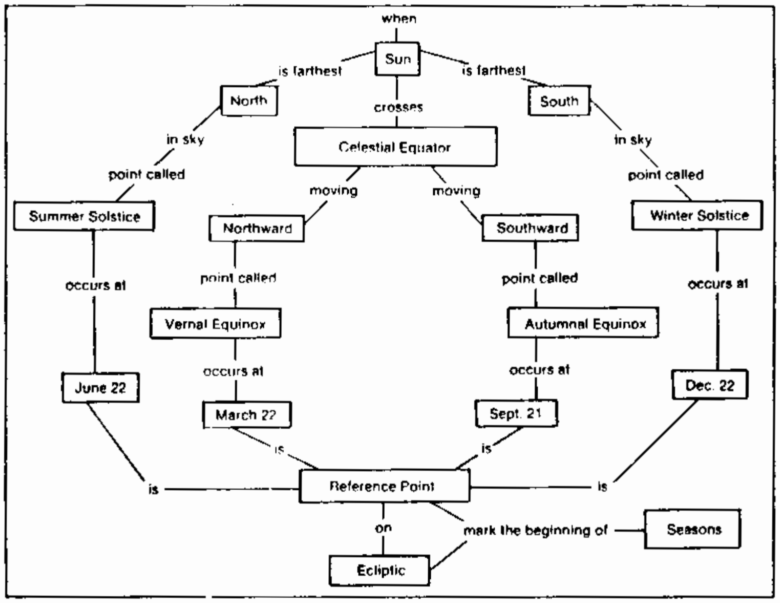

Figure 9. A student-constructed map on "Celestial Equator" that captures the meaning of equinoxes and solstices as both calendar dates and positions of the sun in the sky.

and learnable only through tedious memorization. Some believe they must remember information precisely in the form presented or be penalized. They may fear that attempts to put ideas in their own words will interfere with accurate recall and make them appear ignorant.

Yet the inflexibility of rote knowledge in novel contexts, its restraint upon critical thinking, too often becomes painfully evident. Struggling with unconnected ideas about complex events unrelated to common experience, students quietly take our course contents and dump them in "sanitary mindfill." Too many will continue to do so unless we call their attention to meaningful learning practices. Meaningful learning requires uncompromising commitment by both teachers and students to an understanding of structure in knowledge. Concept mapping skill leads in this direction. □

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Some Aspects of Student Understanding of Soil

By
John C. Happs

Introduction

One of the underlying assumptions that is reflected in the Learning in Science Project (Freyberg, Osborne and Tasker, 1980) is that science teaching might be improved if attempts are first made to gain some appreciation of the beliefs, expectations and language that children bring with them to the learning situation.

The emphasis throughout the L.I.S. Project has not been evaluative; rather it has strived to probe difficulties by means of small-scale, in-depth studies that can readily be related to science teaching, essentially at the Form 1-4 levels.

Many of the previous in-depth studies from the project have tended to concentrate on areas of physics (Osborne, 1980; Stead, 1980), chemistry (Happs, 1980; Schollum, 1981) and biology (Stead, 1980a; Stead, 1980b). In comparison to these studies, very little research has been conducted into students' concepts and understanding in areas within the earth sciences (Moyle, 1980).

This investigation attempts to focus attention on the topic "Soil". This is seen to be an important teaching area (Happs, 1981a) and is included in the Infants to Standard 4 syllabus; in Section 4 of the Science; Forms 1-4 Draft Syllabus; and with provision for its inclusion in section 14 of the same syllabus. The 1968 science syllabus also introduces aspects of "soil" at the Form 5 level and senior geography programmes may incorporate aspects of soil.

After several generations of the misuse of soils in New Zealand there is now a growing awareness about the role of soils in the environment and their importance as a life-supporting factor. The New Zealand economy is dependent upon basic resources such as soil and water; thus, an understanding of some aspects of soil would appear to be a desirable component in the scientific education of all New Zealanders.

The Investigation

Forty students (6 × F1, 4 × F2, 3 × F3, 5 × F4, 5 × F5, 4 × F6, 3 × F7, 4 × T, 6 × U)[1] from 7 Co-educational Schools, 1 Teachers' College and 1 University, were individually interviewed. Students were selected by their teacher, who was asked to choose students of "average scientific ability".[2]

During the interviews, students were asked to consider a number of samples which were presented to them in sequence. These samples were: a loose portion of topsoil; a section of turf, with ample grass and a well-developed exposed root system; clay; dry grass; sawdust; potting-mix and pebbles. Such samples represented familiar materials which are likely to be commonly encountered outside the science laboratory and, during the interviews, students were asked to describe and identify what they observed.

[1] F1-F7 = Forms 1-7 (11-17 year olds); T = 1st year Teachers' College students; U = 1st year University students.

[2] The investigator considered that students were average to slightly above average in most cases. F6 and F7 students studied science subjects and geography, at the time of interviewing.

This line of questioning was shaped towards eliciting the students' concept of soil and soil development.

An explanation of phenomena, and their possible links within the environment, was sought, in terms of the students' own ideas. It was emphasised that what was required was the students' own explanation and viewpoints and that there would be no emphasis placed on "right" or "wrong" answers. The interviews were maintained in an informal and "non-threatening" atmosphere throughout.

1. What is Soil?

The first part of the interview[3] attempted to ascertain whether, or not, students recognised soil samples as such, whilst investigating those characteristics that were assigned to soil. General questions such as "What do you see there?" and "Why do you call it that?" were used.

Seventeen students (4 × F1, 1 × F3, 2 × F4, 4 × F5, 3 × F6, 2 × T, 1 × U) used the words "dirt" and "soil" as synonymous terms and did not envisage any differences between the two. However, the majority of students did point to differences between dirt[4] and soil although their criteria were often not the same:

> "dirt's got little insects and that in it" (101)[5]

Older students tended to be more specific:

> (*"Those two terms 'dirt' and 'soil', to you, are they the same or are they different terms, or what?"*) "Dirt, I think, is what you call any stuff in the ground — soil is more like what you plant things in — sort of, it's got more goodness and that in it." (804)

Only 1 student (1 × U) defined soil in terms of its dynamic character and its mineralogical and organic constituents. Descriptions from other students tended to be related to the physical nature of the soil:

> (*"If I were to put a sample of something else down there, how would you decide whether, or not, it was soil?"*) "Well, you could tell by the colour of it and how it felt and what it smelt like." (702)

The bulk of responses to this kind of question, however, were met with answers relating to soil's ability to support plant life:

Only 2 students (1 × F1, 1 × F3) did not describe soil in terms of it being a medium for plant growth. This reference to living things was predominant:

> "soil is a substance that's under the ground and helps growth of plants and things like that". (105)
>
> (*"What do you mean by soil?"*) "More or less what can support plant growth." (904)

A response related to the number and role of soil organisms was provided by a younger student:

> "oh, there's untold living things in soil. They have to live there for protection and live there for a home kind of thing and that's just where they live to get food and that." (201)

However, less informative responses were offered by more experienced students:

> "Some living things depend on soil. There are quite a few living things in the soil". (*"What sort of living things?"*) "Bugs" (*"Can you name any of them"*) "No". (502)

and

> (*"What are they (living things) doing in the soil?"*) "Eating it" (802)

One student (1 × F6) gave a response that approximated a scientist's view of soil with regard to its inorganic and organic components:

> (*"What, to you, would make up a soil, if you were deciding whether something was a soil or not?"*) "Gravel and ground up rocks and decomposed material — with living things in it." (603)

2. Where does Soil Come from?

The idea of soil having evolved on site as a result of the interaction of a number of soil-forming factors was not appreciated by the vast majority of students. Sixteen students (5 × F1, 1 × F2, 2 × F3, 3 × F4, 4 × F5, 1 × T) believed that the soils they observed in the Waikato area were formed at the same time as the earth was formed. This was stated explicitly with no reference as to whether, or not, New Zealand existed at the time the earth formed.

> "Umm — I'd say that it's always been there." (*"Since the earth formed?"*) "Yes." (403)

---

[3] Interviews generally had a duration of approximately 45 minutes although this time-span varied between individual students.

[4] The soil scientist is not likely to place any scientific meaning on the term "dirt", regarding it as a slang word with no specific connotation. This is in contrast to the term "soil", which can be scientifically defined.

[5] In this paper, Form 3 students are identified with a three digit number beginning with 3, i.e. 301, Form 4 students with a 4, e.g. 402, and so on. Teachers' College students are identified with an 8 and University students with a 9.

Supernatural explanations were occasionally pointed to by younger students:

> *("How long has it been there — or has it (soil) always been there — or what?")* "Um — since God created it." (103)

> "It's always been there when the earth got created." (104)

Even older students demonstrated that they did not see soil as having evolved over time:

> "I think the actual soil has always been there but — sort of — most of the — like the nutrients and that in it, sort of come from broken down things, like plants and that." (804)

Eight students (1 × F1, 2 × F2, 1 × F7, 1 × T, 2 × U) considered that soil was the product of rotting vegetation and/or animals:

> "I think it came from a rotting litter kind of layer." (201)

> "Well, it's all the dead matter and litter off the trees that has been broken down by the bacteria and that — and all the dead animals and things." (702)

> "Basically a lot of it — I think — comes from plants." (902)

This same student later revealed that no relationship was seen between the origins of topsoil and clay:

> "A lot of it (soil) comes from plants — like the topsoil and that, but the things like clay seem more like it — could be volcanic, or something like that." (902)

Five students (1 × F3, 1 × F4, 1 × F5, 1 × F6, 1 × F7) felt that volcanic activity was the source of soil:

> "When you have a volcano erupting you've got lava coming out — it dries up and turns into stone. It could be something like that comes up and turns into soil." (402)

> "I think it (soil) would be uplifted — from volcanic activity." (604)

> "Well, when we were doing volcano studies we saw how — umm — found out how — umm — lava — umm — the magma rose from beneath and all this. That could have been one process which might have contributed to soil being there." (703)

Seven students (2 × F6, 2 × T, 3 × U) recognised that soil development may involve a multi-source mechanism:

> "It's (soil) been weathered from parent material, like rock, and it's had other stuff added to it — nutrients." (601)

> "From rocks in river beds and seas — grinding against each other and particles getting smaller and smaller and getting either washed over the land or — umm — distributed by wind and stuff like that. Oh, and bird droppings and animal manure." (801)

Similarly:

> "I should imagine general weathering processes and they fetch fresh plants. They die and decay and you'd have your humus laid down. Then you'd probably have animals feeding on the humus and you'd have excretion added to it and man coming along with his fertilizers and water, wind, rain and sunlight." (905)

Some unusual and more idiosyncratic theories of soil genesis were proposed by some students:

> *("If somebody said 'you tell me how that soil arrived there. Has it always been there — has it arrived recently? Or — '")* "Manure from dinosaurs." *("Manure from dinosaurs?")* "Yes". (202)

Also

> "River deposits — mm — stuff which builds up the soil."

> *("Would you find the soils where there were no rivers — do you think?")* "I suppose so." *("Well, how would they get there?")*

> "Umm — like over in Europe — an ice age — due to glaciation and that. When it melts bring the stuff down from mountains and deposits it on the plains." *("So you always see a river involved in soil formation?")* "Yes." (701)

Two students (1 × F4, 1 × F6) had no ideas about how soil was formed:

> "It (soil) has been formed — I don't know how." (602)

Specifically directed questions showed that the idea of soil being a product of the environment and the need for several soil-forming factors was not appreciated by the majority of students[6]:

> *("Why do you not think there would be soils on the moon?")*

> "Because I never heard anyone say there was." (505)

3. How Old Are Soils?

The sample of topsoil was used to ask students about the age of a "typical" soil in the Waikato area. A significant proportion of students visualised soils, presently located in the Waikato, as having been formed at the same time as the earth was formed. Twenty-one students (5 × F1, 2 × F2, 3 × F3, 4 × F4, 4 × F5, 3 × T) stated this explicitly or implicitly:

> "It's always been there." (204)

The word "always" can mean a number of different time spans, depending upon the

[6] Thirty-nine students (all except 1 × U) were not able to relate to soil-forming factors.

age of the student and this was followed up during the interviews:

> "I'd say that it's always been there." *("Since the earth formed?")*
>
> "Yes — virtually — yes."
>
> *("How long ago is that?")* "Oh — millions." *("Millions?")*
>
> "No — about billions of years ago." *("Billions?")* "Yes."
>
> *("What's a billion — to you?")* "About a million million." (405)
>
> "It has probably always been there." *("Since the earth was formed?")* "Yes — the same time or a bit afterwards." *("A bit afterwards?")* "After the world started forming." *("But it's more or less the same age — do you think?")* "Yes." (504)

Three students (1 × F4, 1 × F6, 1 × U) stated that they had no idea of an "age" for soils in the Waikato region and they were not prepared to speculate.

Other "estimates" ranged from less than 20 years (1 × F1, 1 × F6) through less than 100 years (1 × U), 500 years (1 × U), less than 1 million years (1 × F6, 2 × F7), 2 million years (1 × F5), a few million years (1 × F6), to 100 million years (1 × T).

Three students (1 × F2, 2 × U), considered that the soil would have an age that was dependent on when the vegetation, that, formed the soil, started to break down. Similarly, three students (1 × F2, 1 × F7, 1 × U) stated that the age of the soil would depend upon whatever formed the soil and when the process started.

A rate of formation, albeit rather rapid, was offered for New Zealand soils in general:

> "Two metres form in 500 years in New Zealand." (901)

4. How Deep Are Soils?

The hypothetical situation was proposed whereby the student could dig down indefinitely in his/her back garden, checking to see if soil was still there as the depth of the hole increased. The question was asked "How far down do you think that soil would go?" Estimates ranged from 6 inches to about 10 miles, with the following distributions:

Thirteen students (2 × F1, 1 × F2, 2 × F3, 2 × F5, 2 × F6, 1 × T, 3 × U), considered that the average depth of soil would be up to 1 metre:

> "about foot" (101)
>
> "Probably a metre." (803)

Fourteen students (1 × F1, 1 × F2, 4 × F4, 2 × F5, 2 × F7, 2 × T, 1 × U), suggested that the soil depth would be in the region of 1-10 metres, three students (2 × F1, 1 × F7), estimated depths between 11 and 100 metres.

Four students (1 × F1, 1 × F4, 1 × F6, 1 × T) were sure that the soil depth would lie between 100 metres and 1 kilometre with five students (1 × F2, 1 × F3, 1 × F5, 1 × F6, 1 × U), considering soil to be over 1 kilometre in depth.

> *("If you were digging in your garden at home — if you carried on digging down — let's pretend it's possible — how far do you think soil goes down before it run out?")* "A few miles — 3 or 4." (204)

One student (1 × F3), could not provide an estimate of soil depth.

5. What Changes Do Soils Undergo?

Information concerning possible changes that might occur within soil, was probed by asking students to firstly describe the individual samples, with later questions being directed towards possible relationships between materials:

"Do you think that the soil will change at all with time?"

Further opportunity was provided for students to discuss words such as soil, sand, silt, clay, rock and living things. These terms being presented on separate cards so that perceived relationships might be discussed.

Nine students (3 × F1, 1 × F3, 1 × F4, 3 × F5, 1 × F7) failed to see any changes that might be experienced by a soil body.

> *("Do you think the soil is changing at all?")* "No." (104)
>
> *("And the soil that is there today — do you see that as changing or not?")* (shakes head) *("Pretty much the same?")* "Yes." (703)

Some changes suggested were ones that would be considered quite superficial from an earth scientist's point of view.

> *("Does it (soil) change at all, do you think?")* "Yes — when it rains it will get soggy and wet." (501)

Eight students (1 × F1, 1 × F2, 2 × F4, 1 × F6, 1 × F7, 2 × U) were aware of changes to soil, with additions or losses over a period of time.

> *("Do you think it (soil) would change or stay the same?")* "It'll change a little — with water and things like that — erosion." (604)

Twenty-two students (2 × F1, 3 × F2, 2 × F3, 2 × F4, 2 × F5, 3 × F6, 1 × F7, 3 × T, 4 ×

U), did envisage changes to soil with time and these changes were seen to fall into the following categories:

(i) **SOIL → CLAY**

Four students (1 × F2, 1 × F4, 1 × F5, 1 × T), saw the possibility of soil changing into clay and, once again, this was seen to be a result of compression. This physical process was commonly used to explain the link between soil and clay.

(ii) **SOIL → CLAY → ROCK**

Nine students (2 × F1, 1 × F2, 2 × F3, 1 × F7, 2 × T, 1 × U), thought that soil will sink downwards, changing into clay with the increased pressure. The end-point was seen to be further sinking of clay with conversion into rock at a greater depth.

(iii) **SOIL → CLAY → ROCK → SOIL**

Five students (1 × F2, 3 × F6, 1 × T), extended the last model further, to outline a cycle from soil, through to rock. The rock was then seen to be exposed at the earth's surface, by erosion, with rock fragments ultimately adding to the soil. Sub-surface erosion of rock was not recognised by these students.

(iv) **CLAY → SOIL**

Three students (1 × F4, 1 × F5, 1 × U), considered that clay could be changed into soil and one of these students (1 × F5), saw this soil as later changing into rock.

(v) **SOIL → ROCK → SOIL**

One student (1 × U), felt that soil could form rock, at depth, whilst later exposure of this rock could lead to surface weathering. The resulting rock fragments were seen to be a major contribution to new soil developments.

Only one student (1 × U)[7] appreciated the soil forming factors and the dynamic aspect of soil. Sand, silt and clay were described in terms of particle size, (by student 903) with the latter being seen as an important soil mineral, formed by the chemical decomposition of primary rock minerals.

A survey was designed to test the prevalence of ideas that emerged from the interviews (Happs, 1981). These ideas were largely substantiated over a group of 221 F1-7 students.

[7] Student (903) cannot be regarded as being typical within the group of 1st year university students interviewed during this investigation. This student had started the 1980 1st year program in earth sciences at Waikato University but had to withdraw through illness. At the time of these interviews, student (903) had been exposed to several lectures in 1st year soil science, during 1980.

CHILDREN'S VIEWS CONTRASTED WITH SCIENTISTS' VIEWS

A comparison between children's views and scientists' views are summarised in Table 1.

	SCIENTISTS' VIEWS	CHILDREN'S VIEWS	IDIOSYNCRATIC VIEWS
WHAR IS SOIL?	A product of the environment comprising mineral and organic constituents.	A medium for plant growth and a home for small animals.	(a) food for living things (b) synonymous with dirt
WHERE DOES SOIL COME FROM?	Results from the interaction between factors of the environment. e.g. climate, organic material, parent material, topography.	(a) soil has always been there. (b) soil has formed from various materials chiefly vegetation. (c) volcanic source.	(a) God created it. (b) dinosaur manure (c) river deposits.
HOW OLD ARE SOILS?	Different soils have different ages. Soils can be rejuvenated by the addition of recent deposits. Soils in the Waikato range from 1800-15,000 years old, i.e. geologically very young.	More or less the same age as the earth: millions of years old i.e. geologically old.	Less than 5 years in age.

HOW DEEP ARE SOILS?	Soil depths will vary from a few cm (skeletal soils) to 17 metres or more (deeply weathered tropical soils). Most profiles in New Zealand are not likely to exceed 2-3 metres.	(a) few metres (consensus). (b) several hundred metres. (c) several kilometres. (d) extending to the molten core of the earth.	A minority of students envisaged soil depths of only a few cms.
WHAT CHANGES DO SOILS UNDERGO?	The soil body is dynamic and physical chemical and biological processes ensure that soils are evolving continuously with time.	(a) soil does not change. (b) changes only via additions or losses. (c) soil is part of a cycle which results in the transition from soil to clay and/or rock.	(a) clay can change into soil. (b) soil can change into rock which may then change back into soil but only via surface weathering.

Amidst a confusion of ideas, concerning soil transitions, the following "children's" views are also seen to be in need of some modification:

CHILDREN'S VIEWS	MODIFICATION REQUIRED
1. Soil changes to clay.	Clay can be formed as the soil weathers but not all of the soil will be converted, as many students suspect. Clay is part of the soil fraction and not the end product of soil compression.
2. Soil changes to clay and then into rock.	Sub-surface rock (parent material) can weather and contribute to soil development. Soil cannot be "pushed downwards", compressed and turned into rock.
3. Clay can change into soil.	Clay is generally regarded as being one component of soil, resulting from the weathering of minerals that have their origin in the parent material. Clay cannot "change" back into soil.

Summary

The results of this investigation suggest that children and adolescents have views, concerning soils, which are likely to be incompatible with the views held by scientists.

Whenever a student is introduced to a new topic, during a science lesson, (s)he will almost certainly have an existing conceptual framework which relates to that topic. However, there may be special problems associated with those study areas which contain obvious references to everyday terms, such as "soil" and "rock", and it might be considered that aspects of these topics are mutually understood because they deal with the familiar. Thus, the danger exists that teachers might assume that students hold scientifically acceptable concepts, concerning such frequently encountered words. This kind of assumption should be viewed with caution.

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SOME CHANGES IN THE AUSTRALIAN SCIENCE TEACHERS JOURNAL 1983

The 1983 editions of the Journal will be produced by a group of Canberra based teachers. They will work in league with an editorial representative from each State/Territory Association. In catering for the needs of secondary science teachers the group aims at having all subscribers read some part of the Journal.

The Journal will contain the following sections:

Feature Articles
Senior Secondary Science Notes
- Biology
- Chemistry
- Earth Science
- Physics

Junior Secondary Science Notes
Primary Science Notes
Resource Reviews
Teaching Aids
Science Updates
Research Briefs
ASTA News
Who's Who
Letters to the Editor.

Contributions from classroom teachers in each State/Territory are eagerly sought. Such efforts may be channelled through the editorial representative of the local association or directly to the address below.

The guide to contributions shall remain substantially as is, with the exceptions:

i. Feature article (up to 3000 words) authors should submit a photograph, brief professional biography statement, and an abstract (to 100 words).

ii. The Science Notes sections will contain brief contributions (approximately 600 words) on teaching techniques, demonstrations, concept development activities, safety notes, etc.

iii. The Teaching Aids section will contain contributions that can be directly translated into classroom use, e.g., OHP's, puzzles, crosswords, games, worksheets, etc.

iv. Closing Dates:
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Materials and Their Properties
Rocks

from the

Leeds National Curriculum Science Support Project

Children's ideas about
ROCKS

Before reading this summary of children's prior ideas, it may be helpful to look at the Science Map and The Teacher's View so as to have a useful overall perspective from which to view children's understanding.

Introduction

Most of the research which has been carried out on children's prior ideas on this topic has been done in New Zealand. The presence of volcanoes there may explain the frequency with which children classified rocks (and the minerals of which they are composed) as volcanic. Research findings are summarised below under the following headings:

Rock
Mineral
Sedimentary rocks
Igneous rocks
Metamorphic rocks
Crystals
Size of fragments
Mountains and volcanoes
Weathering
Soil
Implications of the research findings for teaching.

Rock

Children recognise rocks by their weight, hardness, colour and jaggedness. The word 'rock' is applied intuitively and often applied to mineral samples [1 2]. To children rocks have to be large, heavy and jagged, smaller fragments being described as stones. Rock is at first regarded as being made of only one substance, with consequent difficulty in recognising granite as rock. Children are also confused when deciding whether a sample is natural or not [1 3], house brick being regarded as rock because it contains some natural material. The opposite view many also be taken: a cut and polished piece of marble is not a rock and is not natural - to be natural, it must be 'untouched' by man.

Mineral

Most children do not associate 'mineral' with rocks [1 2] and are more likely to think of: mineral water, minerals and vitamins or mineral resources. Occasionally, it is suggested that minerals are 'small stones or precious things'. After a particular teaching programme, minerals were treated as being the same as rocks and both words were used indiscriminately to classify rock samples as volcanic (regardless of whether they were sedimentary, metamorphic or igneous).

Sedimentary rocks

Very few children appreciate the relationship between sedimentary rocks and the sedimentary processes by which they are formed [1]. Such rocks are variously described as 'volcanic' and this includes the notion that heat is involved in their formation. Additional confusion arises when children confuse the layers apparent in sedimentary rocks with the cleavage planes often associated with metamorphic rocks[3].

Igneous rocks

Most children in Happs' sample [1], when confronted with specimens of igneous rocks, have no ideas to offer and merely describe their appearance. A small minority associate them with fire or volcanoes.

Metamorphic rocks

The word 'metamorphic' is associated by most children with metamorphosis in animals and they link metamorphic rocks with butterflies and plants in general (sic)[2].

Crystals

Children may classify rock specimens as 'crystal rocks' and 'normal rocks' and the word 'crystal' is used to describe both rock and mineral specimens, but only if the sample is thought to be attractive in appearance.

Size of fragments

The words 'boulder', 'gravel', 'sand' and 'clay' have specific scientific meanings related to the average size of fragments. Children do not have this awareness and they use the words in an everyday way [3]:

Boulder: children usually see a boulder as a larger and rounded piece of material which has rolled down a hillside.

Gravel: this is usually used only to describe the loose material at the sides of roads.

Sand: children associate sand with beaches or desert.

Clay: this is thought of as sticky, orange stuff found underground.

Mountains and volcanoes

Mountains, in Happs' study [4], are described by children as 'high rocks' or as 'clumps of dirt or soil'. A few children think that mountains are made of molten rock or 'rock pushed up' while others think that all mountains are volcanoes (extinct, dormant or active). The term 'a range of mountains' only rarely means a row of mountains to children and most think of cowboy movies or paddocks and feeding grounds.

Some children have ideas that imply that volcanoes occur on fault lines or over weak spots and 'stuff just comes up there'. In some cases, the build up of pressure under the crust is mentioned. In others, earthquakes shaking the region around the volcano are supposed to account for volcanic eruptions. An idiosyncratic view suggest that 'heat builds up and has to get out'.

Happs found that most children are unable to relate in any way to a theory of mountain building which involves plate tectonics.

Weathering

Cosgrove and Osborne [6] found the idea that water expands on freezing a difficult one for children to accept. The most common underlying model is that volume increases as temperature rises.

Soil

Among the common misconceptions about the nature of soil is that soil is 'just dirt' or 'any stuff in the ground' [5]. It is nearly always agreed by children that soil is a medium which is useful for plant growth. They are aware that there are living organisms in the soil and these are assumed to be 'eating the soil'. Children seem to be largely unaware of the role of the living organisms or, indeed, of the identity of these organisms. In some cases, children distinguished 'dirt' from soil by saying that 'soil has more goodness in it'.

The formation of soil is strongly associated with deposition by rivers, although there is an alternative view that soil has 'always been there ever since the Earth was formed'. Idiosyncratic ideas about the origin of soil included the suggestion that soil is 'dinosaur manure', or that it results from volcanic action.

Children's ideas about the age of soil were varied. Some thought it was quite young ('years or so'). Others held the view that soil was as old as the Earth and had been there ever since the Earth was formed. A notion which was widely held was that soil is the precursor of rock and that it changes to rock in the sequence:

soil ⟶ *clay* ⟶ *rock*

Recent research in Portugal [7], USA [8] and England [9] indicates a remarkably similar progression in pupils' concepts of decay. (The research questions put to pupils related to the 'disappearance' of dead animals or fruits on the surface of the soil.) For the youngest children the concept of decay is non-existent: they think that dead things just disappear or they have human-centred notions which do not allow for ideas about continuity of matter after death. All these studies found that the majority of children conceptualise decomposition as the total or partial disappearance of matter. The concept seems resistant to change, with about 70% of 11-13 year-olds giving responses implying a lack of conservation of matter, even after teaching. Pupils were not aware of the importance of material from dead organisms as part of the soil nor of the role of microbes in the process of decay in soil formation. They tended to think that it is insects which break up material once it has started to rot of its own accord. A later concept is that 'bugs' or 'germs' eat the rotted material and that the rotted material 'enriches' or 'fertilises' the soil but it is not part of the soil.

Some Swedish children expressed the belief [10] that all dead material decays to form soil, and the Earth is thus getting bigger all the time. This idea recapitulates historical notions. Very few children seem to be aware of ideas about organic matter changing to mineral matter during decay, or of any other recycling.

Implications of the research for teaching

It has to be borne in mind that the research quoted has been carried out in New Zealand, a country where volcanic eruptions are probably a fairly common experience. It is, therefore, less likely that British children will place the same emphasis on the volcanic origin of all rocks.

The study of rocks can be regarded as part of a study of all materials; they conform in every way with ideas that materials are mixtures of substances (in this case, these substances are minerals). It is clear from much of the research that children have difficulties in distinguishing between rocks and their component minerals. There is a need, therefore, for children to be given opportunities to:

- recognise rocks of different types both as hand specimens and in the field;
- recognise the important characteristics of the three main rock types, preferably in

the field and reinforced with clear photographs which give an indication of scale;

- handle and note the appearance and major characteristics of some minerals and, if possible, to recognise some minerals in samples of rock.

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ROCKS

THE TEACHER'S VIEW

This section outlines those aspects of a deeper understanding which the teacher needs to have in mind whilst working with pupils. Ideas in any aspect of science are constructed at ever increasing levels of sophistication and there are inevitably more sophisticated understandings than can be represented in these brief notes.

Layered Earth

Seismic evidence leads to the view that the Earth is composed of several layers.

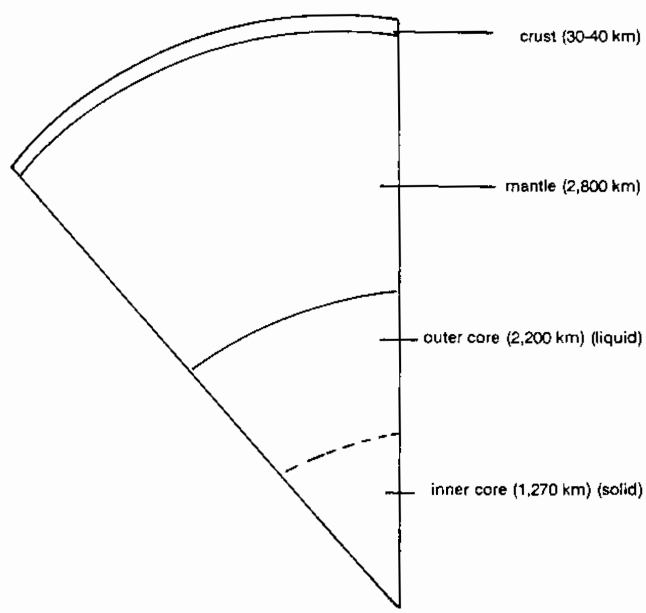


Figure 1 (not to scale)

Rock

The materials of which the Earth's crust is composed are rocks. Rocks are naturally-occurring materials, themselves composed of assemblages of substances (called minerals). Few rocks are composed of a single mineral; one example is marble, a form of the mineral, calcium carbonate. Different assemblages of minerals, in different proportions, give rise to rocks with different properties.

Rocks, like most materials in everyday life, are fairly complex mixtures, and therefore, another word, in this case 'mineral' is useful to refer to the components of the mixtures. Some minerals are elements; others are compounds made up of more than one element. The following diagram (Figure 2) illustrates the make up of a hypothetical rock (material) in which there are three minerals (substances) - one element and two compounds.

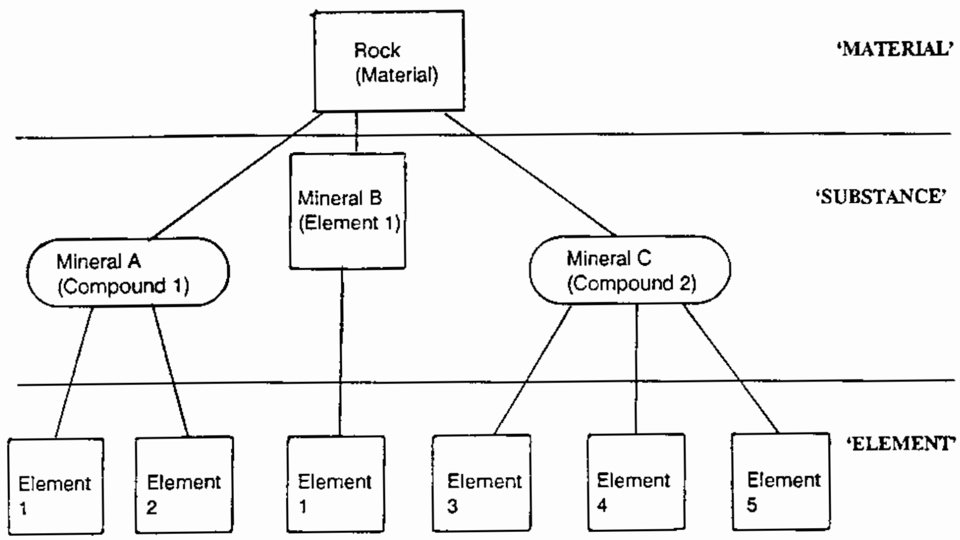


Figure 2: The relationship between 'material', 'substance' and 'element'. (For example, in a sandstone, mineral A would be silicon dioxide, composed of elements silicon and oxygen. Mineral C would be calcium carbonate, composed of the elements calcium, carbon and oxygen.)

Three major rock types can be identified:

Igneous rocks

These have been formed by cooling and crystallisation of molten rock (magma). The magma may be formed in the upper mantle or in the crust of the Earth and consists of molten silicates, water and gases. Magma, being less dense than equivalent solid rock, tends to rise into and through the crust. When it solidifies, the volatile constituents are often lost and the silicates form the igneous rocks. The individual crystals (grains) in such rocks are often large enough to be visible to the naked eye and are usually seen as angular, interlocking crystals. The size of the crystals depends upon the rate at which the magma cooled: rapid cooling such as would occur in magma (lava) extruded under water results in very small crystals, too small to be seen by the naked eye. One example of such a rock is basalt. Granite, however, has large crystals which are associated with magma which has risen to the Earth's crust (intruded) and solidified before reaching the surface.

Sedimentary rocks

Some, like sandstone, are formed from deposits of small fragments (grains) of material which have been eroded from existing rocks which are exposed to weathering on the Earth's surface. Limestone is formed by chemical precipitation of calcium carbonates and often includes the skeletons of small sea organisms. Most sedimentary rocks have formed on the sea bed; as layer after layer of sediment is deposited one upon another, the weight of succeeding deposits both squeezes out water and causes chemical changes in the minerals present. These changes can cause the grains to become cemented together and new sedimentary rock is formed. Sedimentary rocks are characterised by the presence of visible layers - strata or beds - which denote different periods of deposition and can be seen on exposed cliffs or quarries. Sedimentary rocks may also contain fossils of organisms which died and were trapped in the sediments. The type of sedimentary rock formed depends on the type of the parent rock and fineness of the grains.

Sandstone - *small, fairly rounded grains, visible to the naked eye.*
Mudstone - *very fine grains, derived from muds.*
Limestone - *chemically precipitated calcium carbonate containing shells, usually of marine organisms.*

Metamorphic rocks

These are rocks which have undergone physical and/or chemical changes; already existing rocks (which may themselves be metamorphic or igneous or sedimentary) may become buried because of Earth movements. The rocks become enormously compressed and, if buried deeply enough, are heated as well. Examples of metamorphic rocks are:

Marble, formed from limestone.
Slate, formed from shale.
Gneiss, formed from granite.

Mineral

Rocks are composed of minerals. These are either chemical compounds of known, specific composition; or uncombined elements. Unreactive metals such as gold, silver and copper occur as uncombined elements ('native'). The most widespread minerals are the silicates (compounds which always include silicon and oxygen along with various other metal elements). Other minerals include oxides, carbonates and sulphides of metals.

Weathering and erosion

Weathering of rocks exposed on the Earth's surface breaks them down into smaller fragments. The agents of weathering include:

(i) temperature changes, causing alternate expansion and contraction of the rock material;

(ii) the formation of ice in the cracks of rocks (ice-shattering) which occurs because water expands as it cools from 4°C to 0°C;

(iii) the sand-blasting effect of wind-borne sand fragments;

(iv) the chemical effects of rainwater (slightly acidic, with a pH of about 6) on carbonate rocks such as limestone. (This is usually referred to as chemical weathering as opposed to the mechanical weathering described in (i) and (ii).);

(v) the mechanical and chemical effects of plants and animals. (For example, plants which root in crevices in rocks and animals which burrow).

'Weathering' refers only to the breakdown of the rock; without further processes, the fragments remain in situ and the weathering would stop. Erosion happens when the fragments which are formed by weathering are then transported away, exposing fresh rock surface to the effects of weather.

Transport and deposition

Weathered fragments of rocks can be transported by wind: sandy deserts are formed from wind-borne deposits. Sandblasting effects of wind-borne deposits cause further erosion and 'rounding' of the fragments.

Rivers are important agents for the further breakdown and transport of rock fragments. The breakdown of larger rock fragments occurs when they collide with each other and with the river bed or sides as they are carried along by the current. These processes also cause angular fragments to become rounded: the further a fragment has travelled the more rounded its corners. The faster the current of water, the heavier the fragments which can be transported. Wherever the current is slowed down (on the insides of bends or where a river enters the sea or a lake), the fragments are deposited as sediments. The smallest fragments (clays) are carried furthest and are deposited on the sea bed, as changing conditions on meeting the sea causes flocculation of the clay particles.

Size classification

Scientists relate specific diameters to specific terms:

Boulder - *any rock or mineral > 200 mm*
Gravel - *natural, loose accumulation of fragments between 2 and 50 mm*
Sand - *any rock or mineral fragment between 2 and 0.02 mm*
Clay - *mineral fragments < 0.002 mm.*

Soil ,

Soil is not simply 'powdered' rock. Material from the dead remains of plants and animals (humus) together with weathered fragments of the underlying rock form soil. The characteristics of soil in a particular place (colour, depth, porosity, and so on) depend upon the nature of the rock from which it was formed.

Plate tectonics

This is the theory which, in the last 30 years, has revolutionised ideas about the structure of the Earth. Previously, no single theory accounted for all known observations. This theory explains satisfactorily:

(i) the 'jig-saw' fit of the continents and the appearance of particular fossil organisms only in West Africa and the Atlantic coast of South America;

(ii) the pattern of distribution of volcanoes and earthquakes on the Earth;

(iii) the drift of continents over very long periods of time.

It is believed that the crust of the Earth is cracked into several large plates of different sizes; these plates float on the semi-fluid layer of the mantle and are probably carried by giant convection currents in the mantle. Plates move relative to one another in three main ways:

(i) They move apart and magma (molten rock) emerges between the plate margins forming new crustal material. (See Figure 3.) This happens at mid-ocean ridges such as that which occurs in the middle of the Atlantic. As the magma reaches the cold sea water, it is cooled suddenly to form solid rock, forming new ocean floor on both sides of the gap between the plates. Volcanic islands are frequently found over the mid-ocean ridges (for example, Iceland is situated on the mid-Atlantic ridge and has numerous volcanoes).

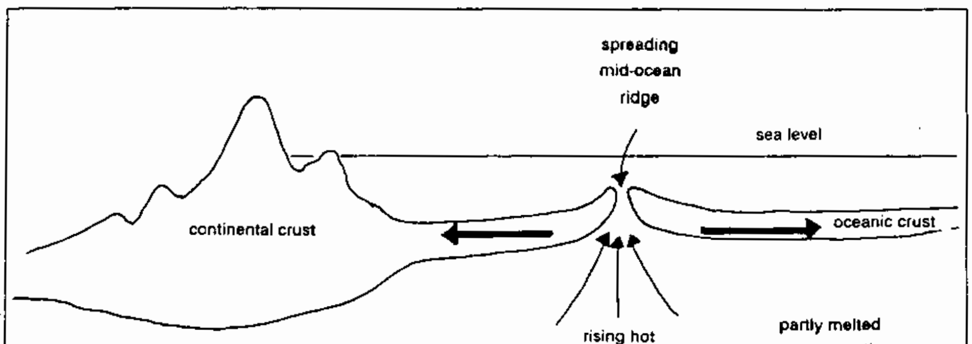


Figure 3: diagram of mid-ocean ridge

(ii) A plate (A) slides down beneath another plate (B); as this happens, the rock of plate A melts and, because it is less dense it rises through the crust forming volcanoes. Continental crust on plate A may become wrinkled up, forming mountain ranges. Such regions, called 'subduction zones', are characterised by the existence of deep ocean trenches, earthquakes and volcanoes .

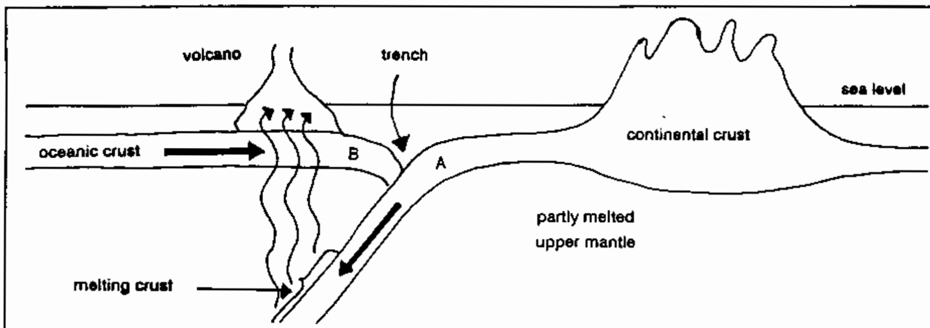


Figure 4: diagram of a subduction zone

(iii) Plates slide past one another but this does not happen smoothly. Due to friction, pressure builds up and its release makes the plates move very suddenly relative to one another; this is an earthquake. The San Andreas fault is of this type.

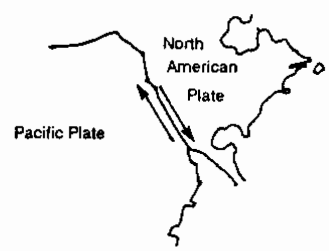


Figure 5

Earthquakes

Regions where earthquakes occur are regions where plates are moving relative to one another. The effects of an earthquake depend on the depth in the crust at which the slippage occurs; the amount of movement; and the way in which different types of earthquake waves travel through the Earth. Earthquake waves register on seismometers in various places on the Earth's surface and their strength is measured on the Richter scale. By taking readings from several seismometers in different places, it is possible to pinpoint where the earthquake has occurred.

Volcanoes

While most volcanoes are associated with plate boundaries, at mid-ocean ridges and subduction zones, some, for example, the Hawaiian Islands, are found in the middle of plates. It is suggested that plumes of very hot material from deep within the mantle rise and break through the crust, forming 'hot spots'. The hot materials emerges as volcanoes. As the 'hot spot' is stationary and the Pacific plate moves, different parts of the crust are subject to the effects of rising plume. This results in a chain of volcanic islands.

Magma, including volatile materials such as water, carbon dioxide and sulphur dioxide, deep in the mantle is less dense than surrounding material and rises through the crust. If the rise of the magma is blocked, by, for example, solidified lava in the throat of the volcano, gas pressure builds up and the magma reaches the Earth's surface explosively. Magma which emerges at the Earth's surface is lava. The several different types of lava vary in composition and viscosity. It is only the viscous lavas, high in silica (silicon dioxide), which give rise to the typical cone-shaped volcano; the basaltic lava from other volcanoes spreads more readily forming shield volcanoes.

Folds and faults

Movements of the plates can cause the crust to become folded and/or faulted (that is, cracked).

Mountains

Mountains can form in several ways:

(i) by volcanic action;
(ii) by folding of rock layers;
(iii) from faults;
(iv) from uplift and erosion of rocks.

Mountain building occurs primarily at the boundaries of colliding plates, where continental crust is crumpled.

Raw materials

The original distribution of the elements of the Earth is very different from their distribution today. The core is composed of iron, the mantle and crust of silicates. Some sulphides are also found in the mantle.

The Earth's crust is the source of raw materials such as building stone, for making cement and other construction materials, and for extracting all metals. Most metals occur in the Earth's crust as compounds. Oxides, sulphides and carbonates are common. Unreactive metals such as gold are found native as the uncombined element. When a deposit of minerals is sufficiently concentrated for its extraction to be economic, the deposit is referred to as an 'ore'. The ore includes the mineral of value (ore mineral), any other but 'useless' minerals (gangue) and the surrounding rock which has to be removed from the crust during extraction of the ore mineral. The increase in concentration of the ore mineral compared with its average distribution has been caused by several natural processes. Examples of a few of these processes follow:

(i) Magma can be regarded as a 'soup' of material; when it cools, the minerals of which it is composed crystallise out at different temperatures. This results in a separation of minerals.

(ii) Watery fluids in the Earth's crust are at high pressures and, therefore, can exist as liquid at temperatures above the normal boiling point of water. At these high temperatures, the water can dissolve minerals which are normally insoluble (particularly sulphides). These solutions then are moved around through cracks in the rock, where they crystallise out forming mineral veins. Such hydrothermal deposits are responsible for the veins of galena (lead sulphide) which are common in the Yorkshire Dales.

(iii) When ancient seas or lakes 'dried up', the salts in solution remained as evaporite deposits. The Cheshire deposit of sodium chloride is of this type.

Fossils

Fossils are found in sedimentary rocks. (The metamorphic processes are likely to destroy fossil evidence in those metamorphic rocks which have been derived from sedimentary rocks.) Fossils provide permanent evidence of life which existed in the past. Fossils include:

- the hard parts of organisms such as shells and bones;
- moulds such as footprints;
- casts such as an infilled shell;
- replaced hard parts, petrified (filled with minerals) such as bones or tree trunk fossils and ammonites.

Only very rarely have the soft parts of organisms been preserved: examples are mammoths in permafrost or sabre-toothed tigers in tar springs near Los Angeles.

The dating of rocks (geochronology)

Radioactive 'dating'

Radioactive minerals found in crystalline rocks can be used to date the rocks. Radioactive minerals contain elements, such as uranium, which have unstable nuclei. The nucleus of an atom in such an element may disintegrate spontaneously (decay) by emitting a particle and energy.

When a nucleus (parent) loses a particle, it changes to the nucleus of a different element (daughter).

The rate at which a particular element decays is constant; it is not affected by any external process and cannot be controlled. Moreover, it is not possible to predict when a particular atom will disintegrate - this is completely random.

The half-life ($t_{1/2}$) is the time taken for half of the parent atoms to disintegrate; the longer the half-life, the smaller the rate of decay. For elements with a very long half-life, the rate is very slow indeed.

The radioactive 'clocks' starts when a rock crystallises and, ideally, when all the element is in parent form. (It is reset when rock recrystallises, as may occur in the formation of metamorphic rock.) The method can only be used if:

(i) no other losses and no other gains have occurred to either the parent or daughter atoms;
(ii) the half-life of the parent is known accurately;
(iii) precise corrections can be made for amounts of daughter present in the rock at crystallisation;
(iv) the actual process of crystallisation of the rock occurred over a short time span relative to the age of the rock.

Usually, more than one dating method is applied, using different radioactive elements and their daughter products. Agreement between the results implies a confidence in the final value.

Fossil 'dating'

Fossils cannot be used to find the absolute date of formation of a rock; however, since particular organisms lived and died at particular times in the past, and, as a general rule, younger rocks lie on top of older rocks, a fossil sequence is useful in finding the relative ages of rock layers.

For example, supposing in one place, fossils a, f and k are found in rock layers A, F and K. That is:

Rock layer		*Fossils*
K	*youngest*	*k*
F		*f*
A	*oldest*	*a*

Many miles away, another sequence of rocks is visible:

Rock layer	*Fossils*
M	*m*
K	*k*
F	*f*

and by amalgamating the two we can extend the sequence:

Rock layer	*Fossils*
M	*m*
K	*k*
F	*f*
A	*a*

In yet a third place, a different sequence is seen:

P	*p*
K	*k*
A	*a*

Layer F is missing - perhaps eroded away before layer K was deposited.

It is not possible from this information so far to place P in the sequence - it is clearly younger than A and K, but its position relative to M can only be determined when further sequences of rock layers are found, which show K, M and P.

The rock cycle

All the geological processes can be summarised in the Rock Cycle (Figure 6 below). It shows how rock material is continuously recycled; this recycling takes place over a very long time scale.

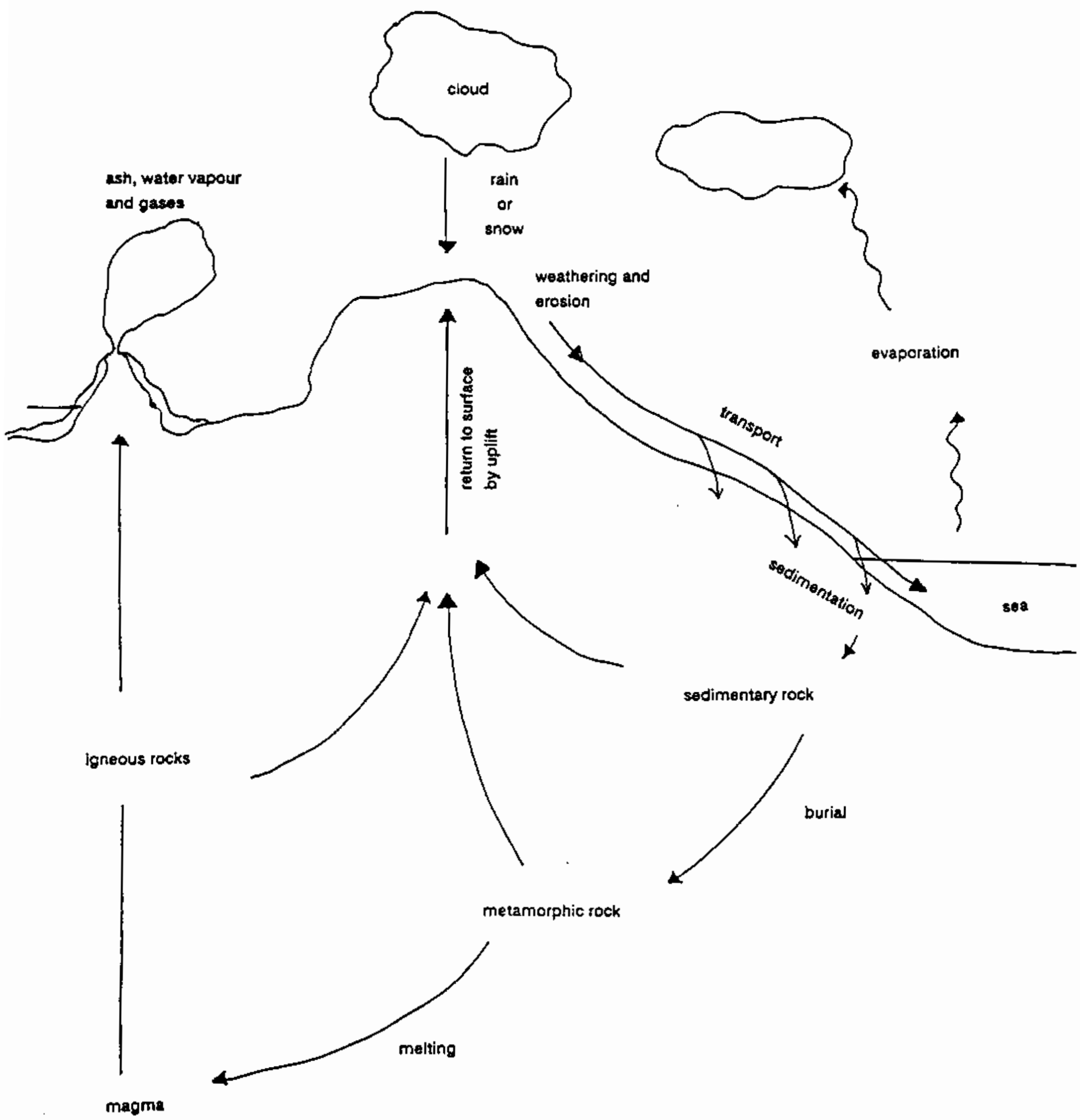


Figure 6

ROCKS

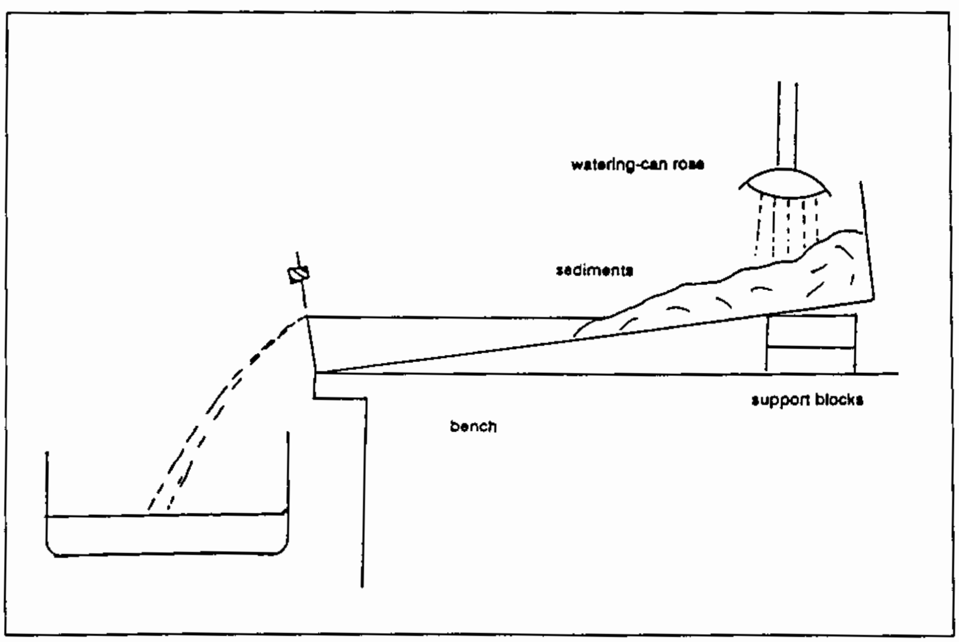
PRACTICAL EXPERIENCES WITH ROCKS

Stream table

Suitable dimensions for a stream table are 1.5m x 0.5m x 0.1m (it can be smaller, but the larger the better). It can be made from a disused drawer or large, shallow tray lined with plastic sheeting to make it waterproof.

Outlet holes can be drilled at different heights; those not in use are plugged with rubber bungs. The outlet holes should drain into a large container (aquarium, bucket) in the sink to prevent sediments being washed out into the sink, causing drainage problems. The rose from a watering-can provides the 'rain' and suitable test materials are mixtures which contain a range of fragment size including sand, clay, pebbles and so on. Even a spadeful of garden soil can be used. It is a good idea to put a small piece of turf directly under the 'rain' to prevent too rapid erosion of the 'sediments'.

The stream table can be left running for long periods of time and can be used to investigate a range of phenomena. Details are given in Making Patterns 2, (pages 74 and 308) and Science of the Earth, (Unit 4). (See Additional Materials: A List of Resources.)



Other stream investigations
Real streams can also be studied in a range of ways: speed of flow of water compared on the inside and outside of bends and related to deposits of sediment; sampling the water and examining it for suspended material and for dissolved material, and so on.

Making sedimentary 'rocks'
Put a quantity of sand in some hard water in a bucket and leave until it is dry; by the end of about a week, it will have set hard, making sandstone. [Hard water can be made by bubbling carbon dioxide into limewater (calcium hydroxide solution) until the precipitate first formed has disappeared again; this results in a solution of calcium hydrogencarbonate (calcium bicarbonate).]

Modelling folds and faults
Plasticine in different colours is the ideal material for making models of folded rock and of faults in rock; different colours can used to represent different rock layers. Layers of coloured felt or a telephone book can be used in the same way.

A wrinkled table cloth models the way in which folds form in rocks.

Porosity of rocks
The porosity of different rock types can be studied and compared by weighing samples before and after immersing in water. Coarse millstone grit is a good example to demonstrate that rocks do absorb water (this is the rock type making up the Cow and Calf rocks at Ilkley).

Weathering
Differential weathering of different minerals can be seen by examining, for example, the statue of the Black Prince in City Square, Leeds. The statue is made of Aberdeen granite and the different minerals are visible as different crystals (grains). If fingers are run over the surface of the granite, it is possible to detect the pitting that has occurred - the feldspars have been weathered leaving behind the more resistant micas and quartz.

The factors which are responsible for weathering can be investigated:

- samples of rock can be left in a freezer and oven alternately (extreme temperature changes). Results are slow to achieve and demands a long term commitment to remembering to change the samples over!
- samples of porous and non-porous rock can be soaked in water and frozen in a freezer (ice shattering);

The Earth's mantle *is* solid: teachers' misconceptions about the Earth and plate tectonics

Chris King

Misconceptions about the state of the Earth's mantle and plate tectonics seem to be common, even amongst those teaching the topics. How can these be overcome?

The state of the Earth's mantle

Why do so many people get it wrong?

Questions about the state of the different spheres of the Earth (from lithosphere to inner core) formed part of a questionnaire completed by 61 science teachers who attended Earth science INSET workshops. They were asked to label the state of each of the sections shown in a 'sliver' cross-section of the Earth (Figure 1) as solid; liquid; mostly solid, some liquid (= partial liquid); or mostly liquid, some solid (= partial solid). Their answers are summarised in Figure 2. In addition to the misconceptions about the mantle, discussed

ABSTRACT
Many science teachers who are asked questions about the scientific background to plate tectonics, get the answers wrong. This is not surprising because rarely have they received teaching in Earth science during their own education. Their main source of information on the subject is science textbooks for 11–16 year-olds, some of which contain errors, whilst some double-award syllabuses and examinations also contain errors. This article discusses the misconceptions revealed by the teachers' answers. It outlines more accurate answers and explanations based on established evidence and uses these to provide a more complete understanding of plate-tectonic processes and the structure of the Earth. Details are given of interactive INSET on this topic provided by members of the Earth Science Education Unit based at Keele University.

below. Figure 2 shows that half the teachers who responded did not realise that the outer core is liquid and that a third did not know that the inner core is solid.

The lower mantle

The Earth's lower mantle is solid, as indicated by the seismic evidence, so why, when questioned at the beginning of INSET sessions, did more than 80 per cent of science teachers think it is either liquid, a partial liquid or a partial solid? Only 10 of the 57 people who answered the question gave 'solid' as the correct answer.

There seem to be good reasons for this misconception, as follows.

- A separate survey of 162 teachers currently teaching National Curriculum for Science (NCS) Earth science showed that nearly two thirds of them had been taught no Earth science during their own education, whilst most of the remainder had been taught very little.
- The main source of information that the teachers used for their Earth science teaching, according to the same survey, was key stage 3/4 science course textbooks (books for 11–16 year-olds). Some of these contain erroneous information about the Earth (e.g. a textbook* published in 1997 with a cross-section of the Earth carrying a label, *'outer mantle made of magma'* and another diagram with the mantle labelled as *'hot, sticky molten rock called magma'*).

- Some GCSE double-award science syllabuses (for 14–16 year-olds) contain errors (e.g. one current syllabus* states *'The Earth has a layered structure consisting of ... a semi-solid mantle ...'*, and another*, *'At plate boundaries, plates move towards each other, taking rock into the magma'*).
- Some double-award science examination questions also contain errors (e.g. the 1998 specimen questions from one Board* refer to the *'molten mantle of the Earth'* and the 1996 examination from another Board* shows the mantle as semi-solid). The Earth-science content of double-award science syllabuses and examination papers is discussed in detail in King *et al.* (1998, 1999). These indicate the scale of error and oversimplification in current GCSE syllabuses and exams.
- Some magmas do come from the mantle; however no magmas have been detected coming from the lower mantle.

The upper mantle

The seismic evidence for the upper mantle indicates a narrow zone that contains a small amount of molten material, but is nevertheless 90–99% solid; this is the asthenosphere. When the science teachers were questioned about the state of the asthenosphere, nearly half of them correctly thought it was a partial liquid, but more than a third thought it was completely solid.

In certain parts of the Earth (the constructive plate margins), where temperatures are high and pressures are relatively low, molten material from the asthenosphere can migrate and accumulate in magma chambers, to provide the source of magma for constructive margin volcanicity.

Why does it matter?

It might be argued that knowing the states of the different spheres of the Earth is not important to teachers who teach the Earth science component of the NCS. However, if pupils are to gain a scientific understanding of the evidence concerning the structure and properties of the Earth, and of the explanations we have for these characteristics, then a knowledge of their states is crucial.

Current understandings and the seismic evidence for them are summarised in Table 1. It does not include data on the crust. This is because the Earth spheres included in the table are defined by their mechanical characteristics (their states), which is critical to the understanding of plate tectonics. The boundary between the crust and the mantle is not a mechanical

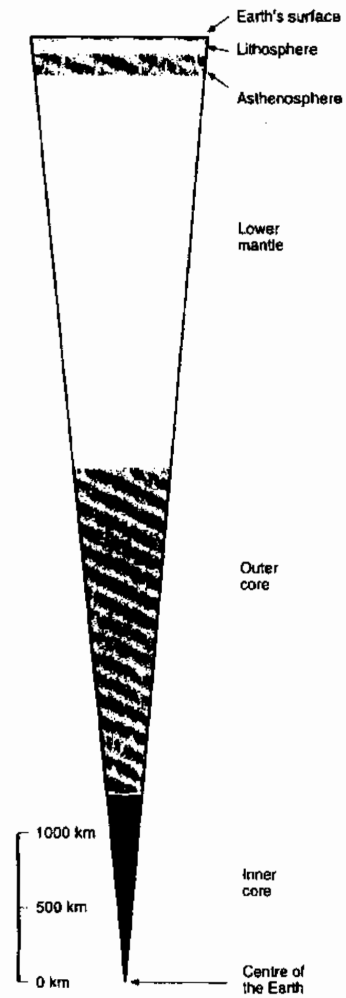


Figure 1 The 'sliver' cross-section of the Earth that teachers were asked to label. The diagram on the question paper was 22 cm high, giving a scale of 1 cm to 245 km.

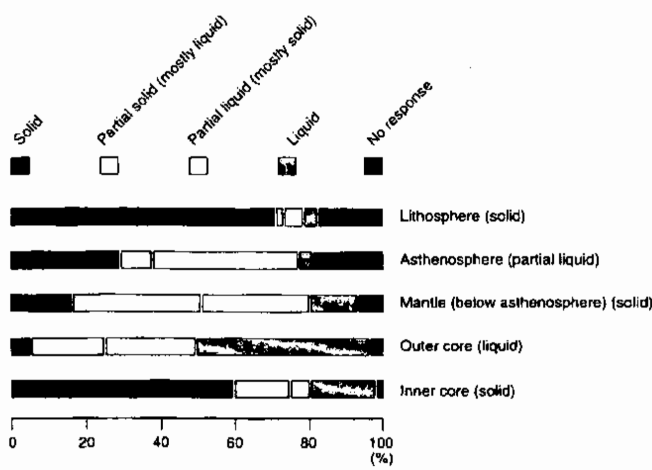


Figure 2 Responses to a question on the state of Earth spheres by 61 science teachers before Earth science INSET (61 of the 76 teachers asked responded to the question).

boundary: it is a chemical one (the crust is made largely of silica-rich, iron-poor rocks, whereas the mantle is silica-poor and iron-rich). This chemical difference results in differences in physical properties that can be detected by seismic waves, allowing the position of the crust/mantle boundary to be detected. However, the crust/mantle boundary plays no role in plate tectonics because the lithosphere comprises both the crust and the extreme upper mantle. Thus it is incorrect to refer to 'crustal plates' as in some syllabuses and textbooks; plates are made of the much thicker lithosphere and so are 'lithospheric plates'.

The importance of this to the understanding of plate tectonics is that the plates, being made of solid lithosphere, are rigid and so can be moved as solid sheets across the surface of the Earth. The asthenosphere beneath is near its melting point and contains small amounts of liquid so that it is ductile. Thus, under the huge pressures and in the great amount of time available, this largely solid material flows, allowing the plates to move. Indeed, we now know that even the solid mantle beneath the asthenosphere can flow under the intense conditions. Many people are greatly surprised to hear about flowing solids but, when they

Table 1 Data on the different spheres of the Earth.

Earth's sphere	*Depth/km*	*State*	*Evidence*
Lithosphere	0—100	solid	'S' waves transmitted
Asthenosphere	~100—~250	partial liquid (90–99% solid)	'S' waves slow down, some slowing of 'P' waves
Lower mantle	~250–2891	solid	'S' waves transmitted
Outer core	2891–5149	liquid	'S' waves not transmitted; 'P' waves refracted
Inner core	5149–6371 (centre)	solid	'S' waves transmitted

Note: The whole mantle (the lower part of the lithosphere, the asthenosphere and the lower mantle together) is 99–99.9% solid.

are near their melting points and pressures are high. solids can and do flow. A more familiar example of a flowing solid is the downhill movement of glaciers.

Is the ductile flow of the mantle the driving force of plate tectonics? This is a matter of current hot debate amongst Earth scientists, some of whom believe that currents of mantle material are the main driving force of the plates. Others believe that the subducting part of the plate sliding down into the mantle drags the plate across the surface. Still others believe that the sliding of lithosphere off the high oceanic ridges pushes the plates along. Finally, other Earth scientists consider that plates are moved by a combination of all these factors. Whichever of these ideas is correct, the ductile nature of the mantle plays a key role, either as a driving force or a means of allowing the lithospheric plates to slide. However, the fact that it is ductile does not mean it is liquid, as discussed above.

Knowing the state of the Earth's mantle is important to the understanding of seismic waves as well. Pupils should be taught *'that longitudinal and transverse waves are transmitted through the Earth, producing wave records that provide evidence for the Earth's layered structure'* as stated in the NCS (DFE, 1995). If the mantle were liquid, or even mostly liquid, it could not transmit 'S' waves, since they can only travel through a rigid medium (see below).

The outer core is liquid, but has no direct role in the mechanism of plate tectonics. However, its flow seems to be the generating mechanism for the Earth's magnetic field. Geomagnetic evidence has played an important part in unravelling the plate tectonic story.

How do we know?

Most of the evidence that indicates the structure and properties of the deep Earth is seismic evidence. Indeed, we use subsonic earthquake waves in much the same way as ultrasonic waves are used in medicine (e.g. for scanning the unborn child in its mother's womb).

The two main sorts of waves generated by earthquakes are surface waves and body waves. It is the surface waves that cause damage, as with the recent devastation in Turkey. Body waves travel through the Earth and there are two sorts, the primary or 'P' waves (longitudinal or compressional waves that travel through solids, liquids and gases), and the secondary waves or 'S' waves (transverse waves transmitted only by solids and not by liquids or gases).

Both 'P' and 'S' waves travel through the lithosphere, indicating that it is solid. They both also travel through the asthenosphere, showing that it too is largely solid. However, the fact that they both slow down by some 6% in this zone (the zone of slower travel is known as the 'low velocity zone') indicates that there is some liquid in this region (1–10%). 'P' and 'S' waves travel at increasing velocity through the rest of the mantle, indicating that it also is solid (not 'molten', or 'partly molten' or 'semi-solid', or even 'sticky', as in some textbooks, syllabuses and exam questions).

At the boundary between the mantle and the outer core, 'S' waves are no longer transmitted, indicating that the outer core is liquid. Further evidence for the liquid outer core comes from the refraction of 'P' waves which, as a result, are not recorded in certain parts of the Earth (the P-wave shadow zone) and arrive later than expected in other parts.

Evidence for the solid inner core is more complex. As 'P' waves travel through boundaries within the Earth, they generate 'S' waves and similarly, 'S' waves generate 'P' waves at boundaries. Thus 'P' waves that have travelled through the mantle and the liquid outer core generate 'S' waves at the boundary of the inner core. The 'S' waves that travel through the inner core generate new 'P' waves at the inner core/outer core boundary on the other side, which can eventually be detected on the far side of the Earth. This is the explanation for a set of 'P' waves that arrives on the far side of the Earth much later than expected.

Thus seismic data have produced crucial evidence for the Earth's layered structure as well as for the mechanisms that cause plate movements.

Plate tectonics – evidence and explanation

Plate tectonics is now a cornerstone of our understanding of the Earth, from local to global scale. The development of the theory in the 1960s revolutionised our understanding of the planet on which we live. Many of the insights it has provided continue to be explored today. Plate tectonics is taught to pupils at key stage 3 (11–14 year-olds) in geography, but usually as a factual model. If science teachers are to take this factual knowledge and treat it scientifically, then scientific evidence and explanation must be introduced to build on, and extend or modify, pupils' prior knowledge.

The scientific evidence and explanation approach is the focus of the 'Plate Tectonics Interactive' workshop being offered at minimal cost to schools by the Earth Science Education Unit based at Keele

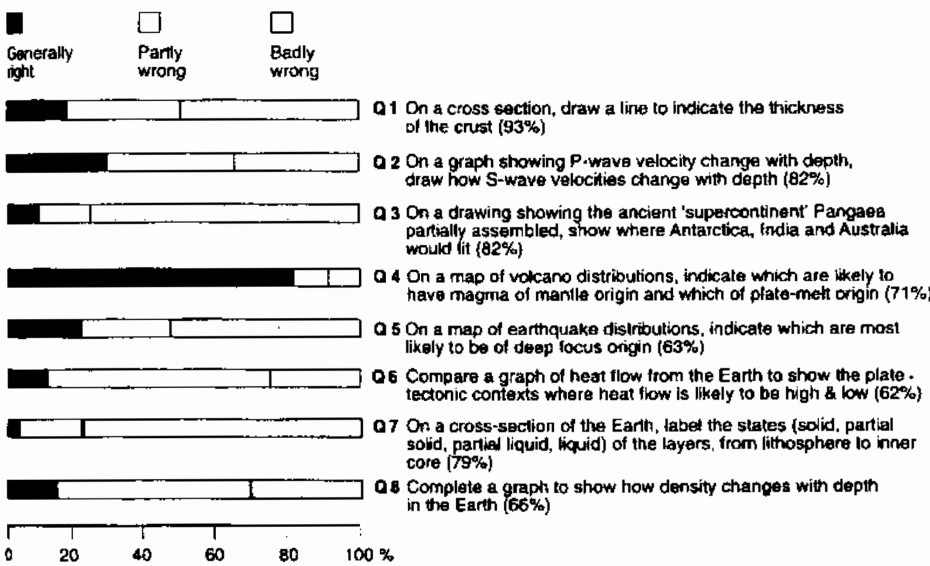


Figure 3 Teachers' responses to questions on plate tectonics and the structure of the Earth before Earth science INSET (the percentage of the 76 teachers who responded to the question is shown in brackets).

University. In the workshop, science teachers are taken stage by stage through the 'facts' of plate tectonics (most of which are hypotheses), the evidence we have for them and explanations for the mechanisms that drive them.

The data on misconceptions about the Earth spheres, discussed above, came from question 7 of a series of eight questions relating to the plate-tectonic evidence and explanation that teachers were asked prior to recent workshops. Their responses to all eight questions are shown in Figure 3; correct answers to the questions are given in Table 2.

Discussion around the questions during the workshop takes teachers well beyond the knowledge and understanding currently necessary for answering most GCSE double-award science questions. It is intended to give teachers a sound understanding, not only of the mechanisms of plate tectonics, but of the methods Earth scientists use to study plate-tectonic processes and their products.

Given that these questions are so closely linked to a scientific understanding of plate-tectonic theory, it is of great concern that so many teachers made significant errors in answering them (in Figure 3 and Table 2, the term 'badly wrong' means that the answer given contained at least two errors and showed major misunderstanding of the factors involved). Of particular concern is that:

- nearly half the teachers asked had no real concept of the scale of the crust relative to the whole Earth and so probably misunderstand the scale of plate processes;
- a third of the teachers had little idea of how 'S' wave velocity changed with depth and the evidence provided by this for the structure and state of the Earth;
- three-quarters of the teachers did not appreciate how the supercontinent Pangaea needed to be reconstructed from the first principle of where the continents are found relative to one another today;
- half the teachers did not appreciate how earthquake-depth evidence can be used to support plate-tectonic theory;
- a quarter of teachers did not appreciate the importance of the heat-flow evidence;
- most teachers had wrong ideas about the state of the different Earth spheres, and
- nearly a third of teachers did not apply physical principles to an understanding of the density of the Earth.

Table 2 The plate tectonic assessment questions, answers and further detail ($n = 76$).

Question	*Answer*	*% of teachers responding who got this badly wrong*	*Importance for plate-tectonic evidence/explanation*
Q1 On a cross-section, draw a line to indicate the thickness of the crust.	The mean continental crust thickness is 33 km. The mean oceanic crust thickness is 7 km. The mean thickness together is about 15 km.	49	The lithosphere, of which the the crust is a part, is only a very thin rigid shell on the surface of the Earth.
Q2 On a graph showing the change of 'P' wave velocity with depth, draw how 'S' wave velocities change with depth.	Below the asthenosphere, 'S' wave velocities rise steadily to the mantle/outer core boundary, where they suddenly fall to zero.	34	Since 'S' waves are transmitted through the mantle, it must be solid; that they do not pass through the outer core shows that this is liquid. Steadily increasing 'S' wave velocities through the mantle reflect increased rigidity.
Q3 On a drawing showing the supercontinent Pangaea partly re-assembled, show where Antarctica, Australia and India would fit.	Most reconstructions put the Antarctic Peninsula of Antarctica between the southern parts of S. America and Africa: India is positioned in the triangular gap between Antarctica and Africa and Australia is adjacent to India, joined to Antarctica.	74	Reassembling Pangaea is not simply a jigsaw puzzle. The current positions of the continents must be taken into account when placing them in their previous positions. If, as in some incorrect answers, for example, India is positioned adjacent to Europe, this shows misunderstanding of the scope of plate tectonic movement.
Q4 On a map of volcano distributions, indicate which are likely to have magma of mantle origin and which of plate-melt origin.	Oceanic ridges have volcanoes that derive magma from the mantle. Volcanoes associated with subduction zones have magma derived from the partial melting of the subducting plate and the asthenosphere above (water carried down by the plate reduces the melting point of these rocks).	9	Plate-tectonic processes are the underlying cause of the chemical differentiation that forms the oceanic crust through the partial melting of mantle rocks. Similar processes form the silica-rich continental crust through the partial melting associated with subducting plates (resulting largely from their high water content).
Q5 On a map of earthquake distributions, indicate which earthquakes are likely to be of deep focus origin.	Deep focus earthquakes occur where cold rigid subducting plates plunge into the mantle.	52	Earthquakes become deeper in the direction in which the plate is being subducted. Deep focus earthquakes are therefore evidence for subduction and show the direction of movement of the subducting plate.

Question	*Answer*	*% of teachers responding who got this badly wrong*	*Importance for plate-tectonic evidence/explanation*
Q6 Complete a graph of heat flow from the Earth to show the plate tectonic contexts in which heat flow is likely to be high or low.	Heat flow is greater over ocean ridges, is lower near trenches where subduction occurs and rises again in volcanic areas beyond trenches.	25	The reduction in heat flow adjacent to trenches is evidence for subduction, since it is explained by the slab of cold lithosphere being subducted into the hot mantle.
Q7 On a cross-section of the Earth, label the states of the layers (solid, partial solid, partial liquid or liquid), from lithosphere to inner core.	The answers (see Table 1) are: lithosphere – solid, asthenosphere – partial liquid, lower mantle – solid, outer core – liquid, inner core – solid.	77	This is discussed above. The rigid lithospheric plates are enabled to move by the ductile flow of the partially liquid (1–10%) asthenosphere and the solid lower mantle.
Q8 Complete a graph to show how density changes with depth in the Earth.	Density increases with depth. Sudden increases in density occur at the crust/mantle, mantle/outer core and outer core/inner core boundaries.	30	Density is controlled largely by the pressure of the overlying material, and so must increase with depth. Sudden changes in density reflect changes in chemical composition or physical state.

However, it was encouraging that so many of the teachers were able to link the positions of volcanoes to the sources of magma from which they are derived.

Dealing with the misconceptions

There is heartening evidence that the 'Plate Tectonics Interactive' workshop provided by the Earth Science Education Unit team makes a difference. The limited number of teachers who were asked to complete the plate-tectonics assessment again after the workshop, showed marked improvements in their answers to the majority of the questions. Some of the comments on recent workshops have concluded: *'now have a greater depth of understanding to explain plate tectonics'*; *'have more confidence with improved knowledge'*; *'will include new ideas in our scheme of work'*; *'excellent'*.

Unfortunately, only a few science teachers in recent months have been able to attend workshops provided at Association for Science Education (ASE) and Earth Science Teachers' Association (ESTA) regional and national conferences. Nevertheless, the real need for INSET in this area has been shown by:

- the level of misconception amongst the teachers who teach the Earth science component of the National Curriculum for Science;
- the poor information provided by a number of science textbooks, syllabuses and examination papers;
- the fact that, of more than 100 teachers of Earth science surveyed, nearly a half expressed a high level of interest in attending Earth science INSET and only about 10% expressed little or no interest.

The 'Plate Tectonics Interactive' workshop, aimed at key stage 4 (for 14–16 year-old pupils), begins with a review of the plate-tectonic understanding that pupils might be expected to bring to science from key stage 3 geography. By means of a series of slides and diagrams, and through an emphasis on evidence and explanation, the main plate-tectonic processes are discussed from a scientific perspective. Finally, a series of activities that can be used to consolidate plate-tectonic understanding in a practical way are reviewed and demonstrated. These are all taken from the booklet, *Geological changes – Earth's structure and plate tectonics* (King and York, 1996).

The positive feedback on the plate-tectonics workshop, and the other Earth science workshops on offer, indicates that this interactive-workshop approach can bring interesting, relevant and engaging Earth-science teaching approaches to the people who matter – the teachers who are teaching this material on a day-to-day basis.

Acknowledgements

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*Individual textbooks, syllabuses and examination papers that contain errors are not cited here, since 'naming and shaming' would probably not be constructive in this context. However, the bodies responsible for the errors have been informed and further details are available direct from the author.

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Earth science INSET

Thanks to a grant from the UK Offshore Operators Association (UKOOA), the umbrella body of the UK oil industry, the Earth Science Education Unit based at Keele is able to address the issues in the above article by offering interactive Earth science INSET to secondary schools at minimal cost. The 'Plate Tectonics Interactive' workshop is one of a series of Earth science workshops aimed at the National Curriculum for Science, offered by the Unit. In the three regions in which this approach is being piloted (regions centred on Sheffield, Manchester/Stoke-on-Trent and West Midlands) team members will provide INSET for the cost of travelling expenses and photocopying. Team members can travel further afield to provide workshops to groups of teachers from several schools.

To book one of the team, contact Peter Kennett, Earth Science Education Unit, 0114 2361271 for more details.

Some comments on children's ideas about Earth structure, volcanoes, earthquakes and plates

John G. Sharp, Margaret A. P. Mackintosh & Paul Seedhouse

Introduction

National Curriculum orders continue to require that children study the nature, cause and effect of earthquakes and volcanoes, including the human response towards them, and this is welcomed. Whether implicitly at Key Stage 2 or explicitly at Key Stage 3, it seems more than appropriate that learners of all ages be given the opportunity to investigate globally significant events which, amongst other things, affect the lives of many year after year.

Surprisingly, however, very little information exists regarding primary children's ideas about such matters. What does is summarized briefly as follows. Ross and Shuell (1993) determined from ninety one American kindergarten to sixth graders that although children associated earthquakes with shaking and trembling and the destruction of buildings, or the splitting open and cracking of the Earth, most could not describe any causal mechanisms other than through a casual association with volcanoes. A few older children did mention plates but their ideas about plates were not followed up. An interesting association between earthquakes and volcanoes was also noted in secondary aged children from New Zealand by Happs (1982), some suggesting that mountains could become volcanoes if shaken by earthquakes but peaks with snow on could not. Mountains themselves are often thought by some young children to have been made by "God" or "man" out of "stones or dirt" (Piaget, 1929). In a study involving UK children's ideas about rocks, soils and the weather, Russell et al. (1993) determined that infants and juniors had, quite understandably, a poor knowledge of the Earth's internal structure, though some improvement did occur following intervention. Lillo (1994) has provided us with a more detailed and valuable insight into children's ideas about Earth structure from 10 to 15 year olds in the Pontevedra area of Spain. Clearly much basic information still needs to be made available, information which is essential to understanding progression and development throughout all the Key Stages not just in primary.

In this article, we present some of the more exotic and unusual findings of a brief opportunity investigation concerning earthquakes, volcanoes and other related phenomena with thirteen, mixed ability, Y5 boys and girls (9-10 years) from a county primary in Devon. The outcomes were particularly instructive as they gave us an insight into some children's pre-instructional, intuitive and partially informed ideas and the extent to which they could be influenced, with obvious implications for teaching and learning.

Children's ideas

Informal interviews, involving questions and short tasks, were conducted just after the disastrous Indian earthquake in Maharashtra State east of Bombay in September, 1993, in which thousands of people lost their lives in the one town of Khilari alone, and the Los Angeles earthquake of January, 1994, both of which measured c.6.5 on the Richter Scale. These earthquakes were widely publicized at all levels and many of the children could recall their occurrence. Television and other media images of these events clearly had some impact on their ideas.

In the work undertaken here we focused our attention initially on Earth shape, surface features and internal structure. Earth shape might seem an unusual starting point, but many children are known to possess and display 'flat' Earth viewpoints (e.g. Sharp and Moore, 1993) which would be significant when proceeding to explore other areas.

What shape is the Earth? prompted a variety of responses including "round", "ball shaped", "it's a sphere" and "a circle". This was known from books, globes and television. One child provided evidence from another area of the primary curriculum: "Columbus found out when he went around the world."

All chose a sphere from a tray of mixed 2-D and 3-D shapes. Reasons for their choice came from a comparison with the other shapes available and logic e.g. "it's a whole not a half", "if it was a square or a circle you might fall off the edge". When prompted to draw what the Earth might look like from space, all drew a circle, variably annotated with continents, countries, islands, seas, oceans and clouds (e.g. Fig. 1). The difference between a continent and a country was generally not well understood, a common feature in young children. When presented with a physical globe, all of the children recognized it as a model representation of the Earth. Land was easily distinguished from water and some were able to provide the proportion in which they occurred. 'Spherical' Earth concepts seemed likely in all cases.

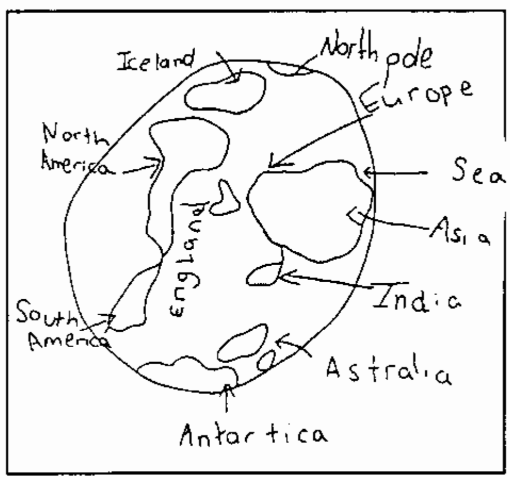

Figure 1. Child's annotated freehand sketch of the Earth.

What is inside the Earth? proved an unfortunate but nevertheless instructive question resulting, unsurprisingly, in the responses "tarmac", "bricks", "skeletons", "pipes", "old stuff", "dead plants" and "centipedes". Modifying the question appropriately we were able to establish that eleven of the sample group thought the Earth completely solid and uniform throughout, the two exceptions describing it as follows (probably from a knowledge of caves):

"It has a middle hole surrounded by earth and soil."
"It might be hollow but it depends where you dig to what you will find."

Probing conditions inside the Earth, five thought it warmer, five cooler and three held mixed views, e.g.:
"The Sun heats up the Earth, it's very hot inside, like tea in teapot."
"It's hot, lots of hot air and rocks burning. It's hotter in the middle.
"It's made of rock there but there's no light. It glows from the heat."
"It's colder in the middle of the Earth because the Sun can't reach it."
"It's cold under .... water is cold that comes from inside the sea and soaks into the ground."
"It's cold inside. Winds blowing make it colder inside .... winds of the Earth."
"Heat comes from the Sun. It will be colder in the winter and warmer in the summer."

Most of the children held a view that the Earth's interior would also be dark, e.g.:
"It will be dark because there's no electricity."
"Underground it's dark because no sunshine gets in."

Probing earthquakes proved effective, probably, as mentioned earlier, a result of the major incidents that had taken place in India and the United States. Responses were very similar to those obtained by Ross and Shuell. Although three children expressed some uncertainty with the concept, most associated the word with a cracking or splitting of the ground, events which could last anything from "10 seconds" to "1 week". Other comments included the following:
"It happens by earth movements, it crushes and shakes .... the land cracks very deep .... they keep happening in the same place."
"They happen in hot countries, it gets hot and the earth cracks. You get some here but you can't feel them because it's not hot here."
"Earthquakes are caused by heat from inside the Earth."
"An earthquake is where a volcano erupts, the ground cracks up because the Sun is really hot."
"When a volcano gets really hot it shakes the land and causes earthquakes."
"God gets really angry."

Some responses indicated confusion with other types of earth movement and process:
"Earthquakes are where rocks move, the rocks are loose so that's why it happens. There are lots of earthquakes near beaches where rocks fall down."

Moving on to volcanoes, we discovered that one child had never heard of them while others were more informed. Most saw them as traditional, conical shaped, surface landforms but were unable to give examples or locations of where they could be found. Comments included:
"A volcano is a little thing with rocks around it .... they are everywhere."
"Lava bursts out when it's hot ... the heat comes from the Sun."
"Lava comes from underground in the core. It comes from the ground up a tube in the mountains."

None of the children had any idea of continental movements or had heard of the word plate used in this context. Plates are, after all, what you get your dinner on!

Intervention

With the short time available to us, we attempted to influence the children's ideas using video materials suitable for their age phase, and by allowing them to carry out several classroom based activities. Some important changes were noted in the post-intervention interviews, only some of which are presented here. Earth structure was better known (e.g. Fig.2) and accounts of earthquakes and volcanoes included the following statements:
"When the land breaks up, one side of the land pushes so hard that it makes the other side of the land suddenly let go."
"The vibrations (caused by the LA earthquake) went through Europe caused by two pieces of the Earth's crust going together and forming an earthquake."
"Magma which is under the Earth moves around, the magma cracks the surface and starts to flow out. This is what we call lava."
"The crater is made by the explosion. The explosion is a large thing."
"Like an earthquake, volcanoes occur where the Earth's crust is weak."

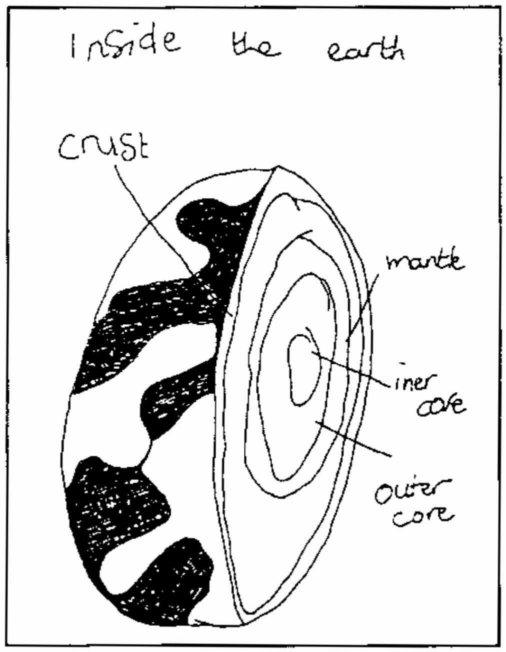

Figure 2. "Inside the Earth". Time did not permit an exploration of the child's knowledge and understanding of the terms used.

Sketches and explanations were often very specific and included the use of much technical language (e.g. Fig.3).

Most of the children seemed happy to accept that at some time in the past the distribution of land masses might have been very different to how they appear today, although their accounts of events varied:
"Large earthquakes split them up and they kept floating until they stopped at a certain place."
"Land may split and float away caused by earthquakes and volcanoes."

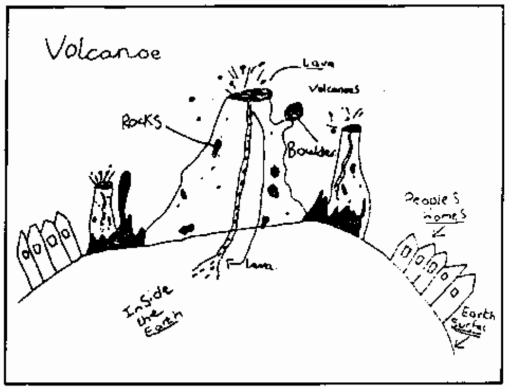

Figure 3. "It's like a mountain. Lava from the centre of the Earth erupts and comes down. Heat causes the lava. It looks red, shiny and hot. It's soft but settles and hardens and becomes rock. It can change the Earth, make rocks and change houses."

"A plate explosion moved them and they floated on water."
"Plates are still moving because earthquakes still exist."

Conclusion

The fact that children's explanations and accounts of natural phenomena, familiar or abstract, often differ from currently accepted scientific views is well known and documented. In the examples presented here, it seems reasonably clear where members of the sample group were drawing on their own everyday experiences as well as other sources to help them. Even after some intervention, individual responses were not always what we expected. In some instances, the children appeared to have at least been sufficiently challenged to consider the new information presented to them and their own interpretation of it. In one case concerning plates and plate movements, for example, it was said that:
"Water may split them apart. Floating can't work because you'd feel them move."

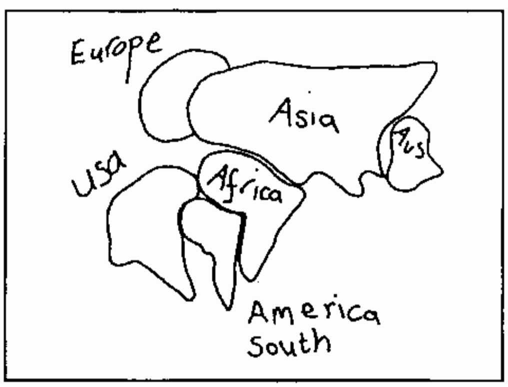

Figure 4. Child's sketch of previous landmass distribution from their own 'best fit' reassembled continent 'jigsaw'.

Within a constructivist model of learning, the ideas and notions such as the ones we have chosen to present and highlight here must be taken seriously by teachers at all levels and appropriate steps taken to help learners accommodate new meaning: easier to say than do. Stimulating and maintaining interest in the areas considered, helping children to find out and clarify their own ideas before and after presenting them with others, and getting them to recognize the significance of what they have found out including its relevance to everyday life must surely be uppermost in our minds.

At Rolle, as a result of this and other small surveys of ideas, we have embarked upon a structured programme of eliciting and clarifying primary children's knowledge and understanding in the field of Earth and Space sciences with the intention of working towards principled teaching strategies to promote effective challenge and, hopefully, change, which we hope to share in the not too distant future.

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Paper Title: Children's understanding of Earth systems phenomena in Taiwan

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Abstract: In the early 1970s, research in science education began to focus on the conceptual learning process that lies behind students' thinking in particular science domains. Much research has been done and is still being done in understanding students' science ideas. These studies show that students coming into a learning environment bring their own conceptions of the world (Osborne, 1984; Engel & Driver, 1986; Solomon, 1985; Gil-Perez & Carrascosa, 1990). Despite what teachers teach about science, many students maintain their early and alternative conceptions of the natural world for several years and even into adulthood. These ideas are constructed by children through their perceptive experiences in daily life. These concepts that children use to explain natural events with respect to their own experiences make sense to them and are therefore difficult for a teacher to change. The ideas students possess prior to formal instruction are considered the single most important factor influencing learning (Ausubel, 1968). Concept learning studies can aid curriculum developers in designing curricula and instructional materials that begin with what students already know and explicitly contrast children's ideas with scientific explanations (Eaton, Anderson, & Smith, 1983).

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Children's understanding of Earth systems phenomena in Taiwan

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INTRODUCTION

In the early 1970s, research in science education began to focus on the conceptual learning process that lies behind students' thinking in particular science domains. Much research has been done and is still being done in understanding students' science ideas. These studies show that students coming into a learning environment bring their own conceptions of the world (Osborne, 1984; Engel & Driver, 1986; Solomon, 1985; Gil-Perez & Carrascosa, 1990). Despite what teachers teach about science, many students maintain their early and alternative conceptions of the natural world for several years and even into adulthood. These ideas are constructed by children through their perceptive experiences in daily life. These concepts that children use to explain natural events with respect to their own experiences make sense to them and are therefore difficult for a teacher to change. The ideas students possess prior to formal instruction are considered the single most important factor influencing learning (Ausubel, 1968). Concept learning studies can aid curriculum developers in designing curricula and instructional materials that begin with what students already know and explicitly contrast children's ideas with scientific explanations (Eaton, Anderson, & Smith, 1983).

Students' alternative conceptions in earth science have been investigated since the 1970's. Although the number of studies dealing with earth science is dramatically less than the numbers of studies in other fields, such as physics, chemistry, and biology, the findings from these studies have provided information to help science educators understand children's ideas about Earth systems. Nussbaum and Novak (1976), Nussbaum (1979), Mali and Howe (1979), Klein (1982), Sneider and Pulos (1982), Vosniadou (1989), and Crews (1990) investigated children's ideas about the shape of the Earth, gravity, and the relationship between the Earth and the Sun. The results of these studies, some of which were cross-cultural and cross-age, showed that many children hold alternative conceptions about the Earth and its gravity. The concept of the Earth develops with age within an individual by a series of transitions from the most egocentric notions to a scientifically compatible one. Jones, Lynch, and Reesink (1987), Sadler (1987), Treagust and Smith (1989), Schoon (1989), Baxter (1989), Dai (1990), and Vosniadou and Brewer (1990) identified students' misconceptions about the Earth, day and night, seasons, and the phases of the Moon. Baxter (1991) also developed an astronomy curriculum and teaching strategy to overcome students' alternative conceptions. Jones, Lynch, and Reesink (1987) also stated that elementary students' ideas about the relationship of the Earth and the Moon closely match the historical development of the scientific explanations. Piaget (1972a, b), Za'Rour (1976), and Stepans and Kuehn (1985) used interviews to investigate children's ideas about wind, rain, and weather phenomena. They claimed that children's explanations of these natural phenomena developed through stages from more animistic, egocentric views to true causality. The findings of concept learning research related to natural phenomena can be of extreme value to science educators. Taking account of children's prior experiences can provide teaching strategies better adapted to students (Driver, 1983).

The focus of this study is an exploration of the conceptions about the Earth systems held by elementary students in Taiwan. The purposes of this research are (1) to identify children's ideas about selected Earth systems phenomena, (2) to investigate the origins of children's beliefs about these natural phenomena, and (3) to describe the characteristics of children's explanations. In this study children's alternative conceptions about three Earth system domains were investigated:

(1) astronomy (day and night, the phases of the Moon, and seasons),

(2) meteorology (rain and wind), and

(3) geology (mountains and rivers).

These topics are all taught in the elementary science curriculum in Taiwan.

METHOD

Twelve elementary school students (one boy and one girl from each of grades one through six) were chosen to find out how they explain selected Earth systems phenomena. To establish trust and gain rich information, the sampling method used in this research was purposive sampling. The subjects were to be children who could easily express their ideas. Having good rapport with them, especially for the younger children, was the priority. Thus, the source of subjects was the children whom the researcher already knew well or school children recommended by elementary teachers.

Each subject was individually interviewed twice with a week between interviews. The interviews took place in school playgrounds, libraries, or subjects' homes. After establishing rapport, an open-ended conversation about interview topics was conducted with each child in an unthreatening atmosphere. The sequence of questions for each interview was changed according to the unique responses of the child. Each interview took thirty to forty minutes. The interviews were tape recorded, and field notes including subjects' drawings were taken. A reflective journal was completed after each interview. Interview strategies changed as the study proceeded to establish better rapport with students and to obtain broader and more in-depth data.

All the interview data were transcribed in Chinese. Three researchers independently checked the transcriptions and coded the data. After consensus discussion between researchers, a final coding list was established from the transcriptions and children's drawings for data analysis.

RESULTS

Based on the purposes of this research, three major categories were used in data analysis: (1) the origin of children's ideas, (2) the types of children's alternative conceptions, and (3) the characteristics of children's explanations. Each category contains a list of subcategories presenting different attributes of the category. The list of subcategories was initially derived from literature review and evolved during data collection. A summarized list of the coding categories is shown in Table 1.

Table 1: The coding list for data analysis

A: The origins of children's ideas.

A1: immediate physical experiences
A2: language, metaphor, and cultural sayings
A3: beliefs and opinions of peers or parents
A4: formal instruction
A5: reading children's books
A6: religious background
A7: television
A8: science museums

T: The types of children's alternative conceptions.

T1: animism--endows objects with feeling, will, or purpose
T2: artificialism--feels everything is intentional and created for the good of man
T3: finalism--possesses a compulsion to explain things
T4: human-made
T5: God-made or supernatural
T6: mechanism--explains things using mechanical processes
T7: scientific ideas

C: The characteristics of children's explanations.

C1: personal
C2: inconsistent
C3: stable
C4: uses logical thinking; the ideas make sense to subject
C5: confuses causes and effects
C6: uses illogical thinking; the ideas are unrelated
C7: subject confuses the information
C8: explanation begins correctly but ends incorrectly
C9: explanation begins incorrectly but ends correctly
C10: incoherent
C11: gives two kinds of explanations simultaneously
C12: uses description as causality

The first major category concerns the origins of children's ideas. The subcategories were drawn from the interview data. Five of the origins, i.e., immediate physical experience, everyday language, metaphor and cultural sayings, beliefs of peers or parents, formal instruction, and religious background, were also stated in earlier studies (Sutton, 1980; Louisa & Veiga, 1989; Hewson & Hamlyn, 1985; Driver & Erickson, 1983; Solomon, 1987). During data collection in this study, children's books, television programs, and science museums emerged as three additional subcategories.

The second major category concerns the types of children's alternative conceptions. The following subcategories, which were found in the interviews, came primarily from the studies by Piaget and his followers (Piaget, 1972a; Fuson, 1976; Stepans & Kuehn, 1985). The definition and an example of each type of explanation are listed below.

1. Animism : Children endow natural objects with feeling, consciousness, and emotion. For example, the first grade girl claimed, "The rain is because clouds are hurt and feel sad, so they cry."
2. Artificialism : Children feel that everything is intentional and created for the good of humans. For example, the second grade girl claimed, "Wind is because it wants to make humans feel cool and comfortable."
3. Finalism : Children possess a compulsion to explain natural events, or children believe that a natural phenomenon is a simple finality in accordance with ordinary common sense, giving little regard to the origins or the consequences of this phenomenon. For example, the first grade boy said, "Spring, summer, autumn, and winter are names of seasons to have different climate. It just changes. "
4. Human-made : Children think that natural phenomena are caused by human powers. For example, the fourth grade girl said, "There are two kinds of mountains. One is made by humans, like you can see these amusement parks in the mountains; those are human-made. The other kind is formed by nature."
5. God-made: Children believe that natural phenomena are caused by God. For example, the fifth grade girl stated, "The King of Ocean manages the rain. Every spring he releases water to the ground to help crops to grow."
6. Mechanism : Children use mechanical processes to explain natural phenomena without involving human qualities. For example, the sixth grade boy said, "When the Earth goes around the Sun, it blocks the sunlight to the Moon. Thus, the shape of the Moon changes."
7. Scientific ideas: Children hold ideas that are accepted by scientists and by their teachers.

The subcategories for characteristics primarily arose during data collection. The findings support the statement in the book by Driver, Guesne, and

Tiberghien (1985) that the characteristics of children's ideas are (1) personal--some children's ideas arise from very personal experiences; (2) incoherent--children's ideas are inconsistent and lack relevance; and (3) stable--children's alternative conceptions exist consistently and are difficult to change. During the interviews, nine other attributes of children's explanations emerged (see Table 1).

<u>About the topics</u>

A summary of subjects' descriptions of each topic is listed in Table 2. The interview topics were chosen from events in daily life with which children are familiar. Most of the subjects had learned these concepts in school. Among the interview topics, the concepts of day and night, rivers, and rain were easier for subjects to understand than other topics. This may be because children can directly observe these natural events. They explained that they had watched heavy rains form small streams on the ground and erode topsoil, and they had seen steam come out of a teapot and condense into water droplets on a cool surface. Although children cannot physically sense the rotation of the Earth, they indicated that they can apply the experience of facing toward and facing away from a source of light to help explain this phenomenon.

The phases of the Moon, seasons, mountains, and wind were too abstract for subjects to comprehend completely. None of the subjects held scientific ideas about the phases of the Moon or the seasons. Even though some children had been taught these concepts in science classes, they misinterpreted what their teachers had taught. Although they used the right terms and correct models, these terms did not correlate with the ideas they had already constructed deep inside their minds. Everyday experiences had also misled subjects' ideas about wind and the formation of mountains.

Table 2. Summary of subjects' descriptions of interview topics

Topic	Brief descriptions	Subjects
Day/ Night	1. The Earth rotates every 24 hours, causing day and night.	6FM,5M, 4M,3F,2M
	2. The Sun goes around the Earth.	5F,4F,3M,2F,1FM
	3. The Sun and the Moon are alive.	5F,3M,2F,1F
Phases of the Moon	1. The Earth blocks the sunlight to the Moon.	6FM,5M,4F,2M
	2. The clouds block the Moon.	4F,3F,1F
	3. The Moon or Sun moves, shifting the shiny part.	5F,4M
	4. The Moon is alive can change its body shape.	3M,2F,1M
Seasons	1. Earth's revolution causes differences in sunlight.	6F
	2. Angle of sunlight to X-axis of Earth's revolution.	5M
	3. Earth is closer to Sun in summer, farther in winter.	6M,4FM,3F
	4. Winds cause the change of the seasons.	5F,3M,2M
	5. The clouds block the Sun and cause the seasons.	1F
	6. Seasons are controlled by ghosts or Gods.	5F,1F
	7. The Sun takes a rest in winter.	2F
	8. Seasons are natural events; no need for reasons.	1M
Moun-tains	1. The Earth's crust movement makes mountains.	6FM,5M
	2. Mountains are formed through erosion by rain.	4FM,3F
	3. Mountains are pushed up by the current of oceans.	2M
	4. Mountains are human-made.	5F,4F,2F,1M
	5. Mountains are for impressing humans.	3M,1FM
Rivers	1. Water in rivers comes from rain, and rivers are caused by erosion.	6FM,5M,4F, 4M,3FM,2M,1F
	2. Rivers are God-made or human-made.	3M,2F,1M
	3. Rivers are tears of children whose mother died.	2F,1F
Wind	1. The convection of cold air and hot air.	6F,4M.
	2. Wind is caused by pressures from ocean and Earth.	6M,5M
	3. Wind is moving air caused by moving objects.	4F,3F,2M
	4. Wind is the breath of the clouds.	3M,2F,1F
	5. Wind is created and controlled by God.	5F
	6. Wind is strong and is related to rain and oceans.	1M
Rain	1. Water evaporates, condenses, and drops as rain.	6FM,5FM,4M,3F,2M
	2. Water evaporates; clouds and winds make it fall.	4F,2F,1M
	3. Rain is the tears of the clouds or of a mother.	2F,1F
	4. Rain is created and controlled by Gods.	5F
	5. Rain comes from oceans and has human emotion.	3M

<u>The types of children's alternative conceptions</u>

A summary of the types of explanations subjects held is shown in Table 3. Subjects' explanations suggested a variety of alternative conceptions.

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The results show that the types of explanations used by subjects were more closely related to the characteristics of subjects' thinking rather than the interview questions. Younger subjects were more likely to display animism, artificialism, and finalism. They were more egocentric and defined concepts based on appearances.

Mechanistic ideas were held by older children or those who had reached the concrete operational stage. These ideas developed through logical reasoning and matched students' physical experiences. Because mechanistic ideas make sense to children, these ideas often are more difficult to change and may persist into adulthood.

The idea of "human-made" was found primarily in subjects' explanations about mountains and rivers. Students often confused human-made constructions as part of mountains and rivers, thus believing that mountains and rivers are formed by humans. The idea of "god-made" was held by students who had been strongly influenced by religion either at home or from reading. These supernatural ideas existed with other explanations simultaneously without conflict.

Subjects often used the same type of explanations to explain the causes of day and night, seasons, and the phases of the Moon. Each subject consistently used their own model to represent the relationships between the Sun, Earth, and Moon. While answering the questions, the subjects' alternative conceptions about their models became clearer and made more sense to them.

The origins of children's alternative conceptions

Children's alternative conceptions arise from many different sources. Physical environment appears to have the strongest influence. Subjects actively applied what they had experienced in daily life to explain natural phenomena. Sometimes they misused an analogy with which they were already familiar, as in the phases of the Moon changing like a silkworm's body.

Direct perception can strongly influence students' ideas that are more difficult

Table 3: Summary of the types of explanations

Subjects \ Topics	Day/night	Moon	Seasons	Mountains	Rivers	Rain	Wind
6F	Scientific idea	Mechanism	Mechanism	Scientific idea	Partially scientific idea	Scientific idea	Scientific idea
6M	Scientific idea	Mechanism	Mechanism	Partially scientific idea	Scientific idea	Scientific idea	Mechanism
5F	Animism + Mechanism	Mechanism	God-made	Man-made	Mechanism	Partially scientific idea + God-made	God-made
5M	Scientific idea	Mechanism	Mechanism	Partially scientific idea	Scientific idea	Scientific idea	Mechanism
4F	Mechanism	Mechanism	Mechanism	Man-made + Mechanism	Scientific idea	Partially scientific idea	Mechanism
4M	Scientific idea	Mechanism	Mechanism	Mechanism	Scientific idea	Partially scientific idea	Scientific idea
3F	Scientific idea	Mechanism	Mechanism	Mechanism	Scientific idea	Partially scientific idea	Mechanism
3M	Animism + Mechanism	Animism	Animism	Animism + Artificialism	Partially scientific idea + God-made	Animism	Animism + Man-made
2F	Mechanism	Animism	Animism + Artificialism	Man-made	Man-made + Animism	Mechanism + Animism	Artificialism
2M	Scientific idea	Mechanism	Mechanism	Mechanism	Scientific idea	Scientific idea	Mechanism
1F	Animism + Mechanism	Mechanism	Mechanism + God-made	Animism + Artificialism	Mechanism + Animism	Animism + God-made	Animism
1M	Mechanism	Animism	Finalism	Man-made	Man-made	Finalism	Finalism

Scientific idea — Animism — Finalism

Partially scientific idea — Artificialism — Man-made

Mechanism — Two explanations — God-made

Shaded areas show the grade level at which concepts have been taught

F: Female M: Male

to change, such as the idea of the Sun going around the Earth. Unless

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students are challenged by the conflict between their ideas and scientific ideas and rethink these problems, they will keep their alternative conceptions for a long time.

Children's alternative concepts also arise from formal instruction. This research showed that science instruction sometimes did not cultivate students' scientific concepts. One unit in the third grade science curriculum in Taiwan shows that mountains and rivers are eroded by rain and water. Thus, many subjects who had learned this unit thought that mountains are built through erosion by water. Often, students had only superficially learned the terminologies by rote without completely comprehending the ideas. The concept of seasons is taught in the fifth grade science curriculum, yet none of the four subjects in fifth grade or beyond truly understood what causes the seasons. Two of them had learned some of the terminology but did not know how to apply it. The fifth grade girl did not even mention any of the ideas she had supposedly learned about the seasons two weeks before her interview.

Some alternative conceptions held by the younger subjects arose from their formal instruction in subjects other than science. One unit in the first grade Chinese textbook describes how the Sun works hard to help the crops and fruits grow in different seasons. Another story characterizing the Sun and wind with human emotion portrays Uncle Wind competing with Grandpa Sun and blowing a strong wind to block the Sun's energy. These two characters appeared in many younger subjects' responses about wind, day and night, and seasons. These children had not reached the concrete operational stage and could not separate stories from reality. Thus, they usually agreed with what the textbooks said and believed that the Sun and wind have human qualities.

Daily language was also found to be a source of some of these subjects' alternative conceptions. Chinese language describes sunrise and sunset as the Sun coming up from behind the mountains and the Sun falling down into the mountains. Thus, many subjects used this description to explain the concept of day and night, even the fourth and fifth graders who had been exposed to more science instruction. They still believed that the Sun goes around the Earth. In many children's stories, paintings, and daily conversation, people always speak as if the Sun is a moving object, which may reinforce children's alternative conceptions.

Vosniadou and Brewer (1990) stated that the mountains and the sea in the Greek landscape seem related to the fact that Greek children preferred to explain the day and night cycle in terms of the disappearance of the Sun behind the mountains or sea. American children preferred the explanation that the Sun goes down underneath the Earth. Mountains and oceans are also the major landscape features in Taiwan. Subjects in this study used similar expressions to explain day and night as did Greek children. This idea might come from their daily language as well as the direct experience of watching the Sun set beyond the mountains or sea.

Chinese expressions about wind also played an important role in subjects' alternative conceptions. Chinese language describes wind in many different ways. Spring wind is used to describe the wind in spring that is warm and comfortable. Summer wind is a softer breeze. Autumn wind is cool and howling and makes people feel sad. Winter wind is very strong and cold. People use these terms to describe the weather and even their moods in literature and daily conversation. Thus, subjects may have applied this language to the origin of the seasons. Three of the subjects thought that the seasons are caused by different winds.

Language may have also affected subjects in learning science concepts. The word "Earth" in Chinese literally means "ground ball", or a ball-shaped object that you stand on. Thus, every subject knew that the shape of the Earth is round like a ball. They may not have realized that language influenced their ideas about the shape of the Earth. They claimed that this idea came from reading science books, watching television, looking at a globe, or seeing pictures taken from space. One student said, "Of course the shape of the Earth is round; otherwise it would not be called the Earth."

The results also show that some subjects' alternative conceptions came from children's books, especially books for younger children. The authors of these books use stories or personification to motivate students' interests and get their attention. However, younger subjects sometimes could not distinguish stories from reality and accepted stories as fact. For example, the idea of a cold ghost and a hot ghost causing the change of the seasons appears in a series of Chinese children's books containing many stories and games to help preschool children understand the environment. However, after reading these books, the first grader actually believed that ghosts are the cause of the seasons.

Many subjects claimed that science books given to them by their parents or from libraries were the major source of their ideas, especially the students from cities whose parents were more concerned about education. Through reading constantly, some subjects comprehended many scientific concepts. Sometimes they had just learned concepts by rote, but when they started to explain and apply the knowledge they remembered, their ideas became more clear and made sense to them. Subjects exposed to rich science resources showed a higher level of logical thinking.

Religion or family beliefs also seem to have affected subjects' views of the world. An obvious example of the influence of religion was shown by the responses of the fifth grade girl. Her strong belief that natural events are controlled by many different gods affected her ideas about the whole universe. She would usually give a mechanistic answer and then add a god-made notion. In her view, scientific concepts can coexist with supernatural powers without conflict.

Characteristics of children's alternative conceptions

Most subjects responded to the interview questions by thinking and then giving answers that made sense to them. These answers also existed consistently between the two interviews. In the second interview, subjects had more time to reflect upon these topics before answering, and they usually answered the questions more completely and clearly. Only two subjects gave inconsistent answers and used many different types of explanations to describe natural phenomena.

Children's cognitive development is an important factor influencing children's thinking. In this study, animism, artificialism, and human-made ideas appeared frequently in the answers of the younger subjects, in agreement with Piaget. Subjects defined concepts from the physical appearances of objects. The first grade boy used the description of natural phenomena as the cause of these events. Children in this preoperational stage use their direct physical experiences to misinterpret natural events (Piaget, 1972a). For example, in this study some subjects thought that the Sun goes around the Earth, that wind is caused by moving objects, and that black clouds block the Moon and cause the phases of the Moon.

Children in the concrete operational stage are more flexible, organized, and logical when dealing with concrete, tangible information that they can directly perceive. Thus, the phenomena that they can experience in their daily lives, such as rivers and rain, are easier to understand than more abstract topics like the phases of the Moon, seasons, and the movement of Earth's crust. Subjects in this stage primarily used mechanistic ideas to interpret the world around them. The results show that children's cognitive levels are not necessarily related to children's ages. The second grade boy held more logical and objective ideas than some of the older children.

There were differences between the answers from subjects who had been taught science in school and those from subjects who had not had formal instruction in these topics. The former used more scientific terms (such as evaporation, erosion, and revolution) and interpreted them in more technical ways. The latter used everyday language to explain their ideas. For example, the third grade girl said, "Rivers are caused through erosion by water", but the first grader said, "When raindrops fall, they are usually very strong, and they hit the ground and dig a hole to become a very small stream."

While explaining their answers, subjects tried to clear up their ideas. Sometimes subjects would abandon their first responses to a question as alternative conceptions and shift to more scientific ideas. In these cases, they would adjust their ideas when faced with conflicts between different answers. In other cases, some subjects shifted away from the scientific concepts that they remembered toward mechanistic ideas. This shifting depended upon which ideas were stronger and made more sense to the student. Some subjects held more than two explanations simultaneously without hesitation. They accepted that these natural phenomena can have multiple causes.

Subjects' ideas were often the result of interaction between children's ideas derived from the perception of natural phenomena and current science knowledge presented by their teachers, textbooks, and children's books. This demonstrates what Ausubel (1968) proposed about the way children learn: a child assimilates new information into an existing cognitive structure, but in the process of assimilation, components of the intended meaning may become distorted. For example, the sixth grade boy had learned in school that mountains are formed by the movement of the Earth's crust, but in his response to the interview question about mountains, he claimed that typhoons comprise one of the dynamics that cause the Earth's crust to move and build mountains.

IMPLICATIONSFORTEACHING

The recommendations made here are based upon the researcher's observation of the twelve subjects in this study. These recommendations were formulated through interpretations of the study findings. Due to the small size of the sample in this study, the findings may not be representative of all elementary students in Taiwan. The reader is encouraged to personally evaluate these findings and form his or her own conclusions.

For researchers

The interview technique, with its use of follow-up questions, is helpful in revealing a great deal about what children understand about a concept. Although researchers can never truly know what subjects really think, interview still provides opportunities to obtain deep data that allow researchers to make adequate interpretations. The results from interviews can offer fundamental information for further investigation and for teachers to use in adjusting their teaching strategies.

For science teachers

Teachers play an important role in students' alternative conceptions. Children have their own ideas before they enter the classroom. Teachers must realize this and diagnose children's beliefs before teaching. Each teacher can act as a researcher and investigate what students already know by asking appropriate questions. They can then provide evidence to help students confront their own alternative conceptions. Unless teachers identify children's views and design their teaching strategies accordingly, some children's views will not change or may change in unanticipated ways. Teachers also must understand that each pupil is an individual learner who acquires knowledge from many different sources and challenge students' alternative conceptions to make them change their ideas. Thus, teacher training programs should encourage preservice and inservice teachers to be constructivists who see each student as an individual learner. Teacher educators also should enhance teachers' experiences in concept change strategies. Elementary teachers need to become familiar with using concept change strategy: eliciting students' ideas, reconstructing these ideas, applying these concepts, and reviewing changes in ideas (Driver, 1986; Posner, Strike, Hewson, & Gertzog, 1982)

Children's science learning

Providing abundant information and different resources to students is effective in stimulating children's science learning and promoting cognitive development. Many subjects in this study showed that they had learned scientific concepts through reading science books. These subjects learned science concepts just as well as students who had formal science schooling, sometimes even better. Children can learn science from many different sources as long as they are provided with appropriate information. Thus, teachers and parents should expose children to science resources other than their textbooks. This may motivate students' interests and cultivate their science thinking. However, to promote children's science learning, children's science books should present science concepts in a way that is appropriate to the cognitive level of the child. Adults also need to choose children's books carefully and help children to distinguish between what is fantasy and what is reality so that children can understand the scientific concepts behind the stories.

For curriculum designers

Elementary science textbooks should be revised to make explanations of scientific concepts more clear and reasonable. Curriculum designers need to be more aware of children's alternative conceptions and design curriculum materials that explicitly contrast these alternative conceptions with scientific explanations. The concepts presented in textbooks from other subjects need to be carefully evaluated to avoid misleading students' science concepts.

Further research could be conducted in longitudinal studies to show the developmental trends in the subjects of this study to understand how these subjects change their alternative conceptions through time. More case studies should be completed to explore individual learning styles to better understand children's thinking. A diagnostic instrument could be designed according to the results of this study to evaluate students' understanding of Earth systems. Research in concept change strategy also needs to be developed to help students overcome alternative conceptions. The success of science learning will depend on uncovering children's beliefs that cause alternative conceptions and on discovering the appropriate instructional strategies for changing these alternative conceptions.

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7 Children's Understanding of Astronomy and the Earth Sciences

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One of the most compelling images depicting the birth of humankind's modern understanding of the universe features a medieval monk pulling back the sphere of primary perception to reveal the cosmos that lay hidden behind these initial ideas (Fig. 7.1). The monk's view, although dangerously controversial at the time,[1] has permeated almost all cultures over the past 400 years and it is now commonly assumed that children and adults draw back the same sphere-like veil to gain a similar perspective. But over the past decade there has been a growing body of evidence that throws doubt on the assumption that children and scientifically naive adults form post-Copernican notions about planet Earth in space (see Durant, Evans, & Thomas, 1989). Research shows that pupils frequently come to their lessons having constructed their own explanations for many of the easily observed astronomical events, and that these children's notions or "alternative frameworks" (Driver, 1983) are at variance with accepted views, often persisting into adulthood.

The work of Nussbaum and Novak (1976) and Sneider and Pulos (1983) showed that children's ideas about planet Earth in space and the gravitational field develop from a naive flat Earth notion through a series of phases to the accepted view. These phases cut across cultural boundaries; Mali and Howe (1979) and Klein (1982) identified similar notions and phases of development in children from a number of different cultural backgrounds.

[1]This woodcut is not what it is often claimed to be. It is pure art nouveau, first published by Camille Flammarion in 1888 (see Gingerich, 1988).

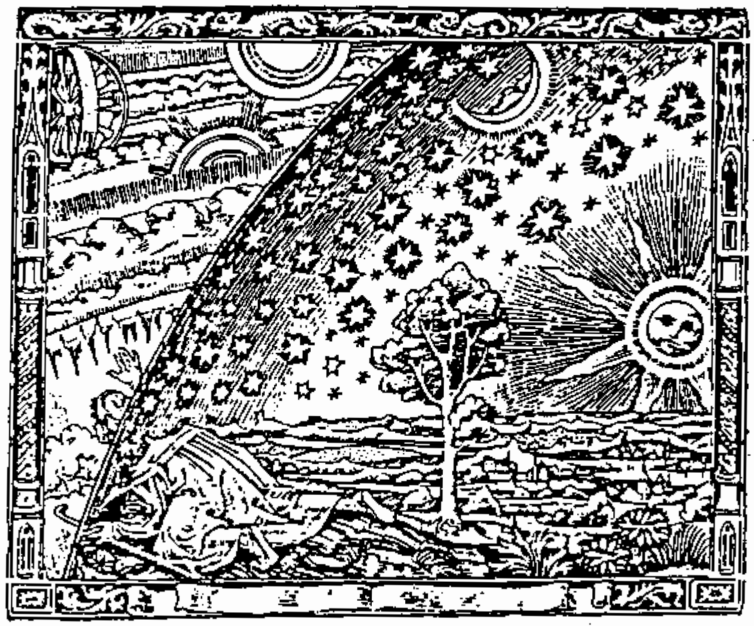

FIG. 7.1 A medieval view of the cosmos.

Research into children's ideas about other science areas—for example, evaporation (Russell, Harlen, & Wall, 1989) and sound (Linder & Erickson, 1989)—shows that pupils frequently construct their own explanations for many of the fundamental concepts of the science curriculum. This growing body of data on pupils' alternative frameworks has given rise to the *constructivist* or *alternative conceptions* movement, ACM (Gilbert & Swift, 1985). The principal axiom of the ACM is that a child's alternative framework is analogous to a scientific theory and will only be exchanged when it is challenged and fails to hold good in the light of new evidence.

Millar (1989) claimed that the ACM has brought science education research into the classroom, but research into alternative frameworks usually involves lengthy interviews with pupils to uncover their particular notions. Limited time and large numbers of pupils in each class preclude this as a commonly practiced classroom activity, and, as with so much science education research, the transition from research data to classroom practice is not always clear.

If research into alternative frameworks is to influence teaching strategies, it needs to be more than an inventory of pupils' ideas; it needs to inform teachers about trends in the progression of these ideas, to demonstrate ways in which pupils defend their notions when they are challenged, and to give examples on how children's alternative frameworks can become the central focus of a teaching strategy.

With these aims as the primary target, the author set up a research program into alternative frameworks about astronomy. This was recently undertaken in Great Britain. Astronomy was selected for two principal reasons. First, almost all children have some experience of the easily observed astronomical events and, in all probability, have constructed their own explanations for these changes long before they enter school. Second, there was a need to promote the more widespread teaching of astronomy in schools.

COLLECTING PUPILS' IDEAS ABOUT THE EASILY OBSERVED ASTRONOMICAL EVENTS

In this research program, children's theories about four astronomical domains were investigated:

1. Planet earth in space and the gravitational field.
2. Day and night.
3. Phases of the moon.
4. The seasons.

The sample of pupils between 9 and 16 years old was taken from pupils attending a comprehensive school in a semirural area of southwest England and its four feeder primary schools. At the time of the survey the schools did not feature astronomy in their science curriculum.

A two-phase process of data collection was used. First, 20 pupils between 9 and 16 years old were interviewed individually about their theories concerning the four domains. The sample covered the full range of abilities (based on their teachers' judgments) and included five pupils from each of the age groups 9–10, 11–12, 13–14, and 15–16, including equal numbers of boys and girls. The interviews were audiotaped and transcribed and records of pupils' drawings were kept. Second, the commonly occurring conceptions were used to construct an astronomy conceptual survey instrument. This comprised a series of statements with supporting diagrams based on the drawings produced by the interviewees. Pupils responded to the statements and their accompanying diagrams by placing a mark on the face that best represented their view (Hearty & Beall, 1984); see the example in Fig. 7.2. This instrument was administered to a representative sample of 48 boys and 52 girls from the same four age groups as the interviewees.

Results of the Survey

For clarity of presentation, the results from the original interview for each domain investigated are followed by the results obtained using the as-

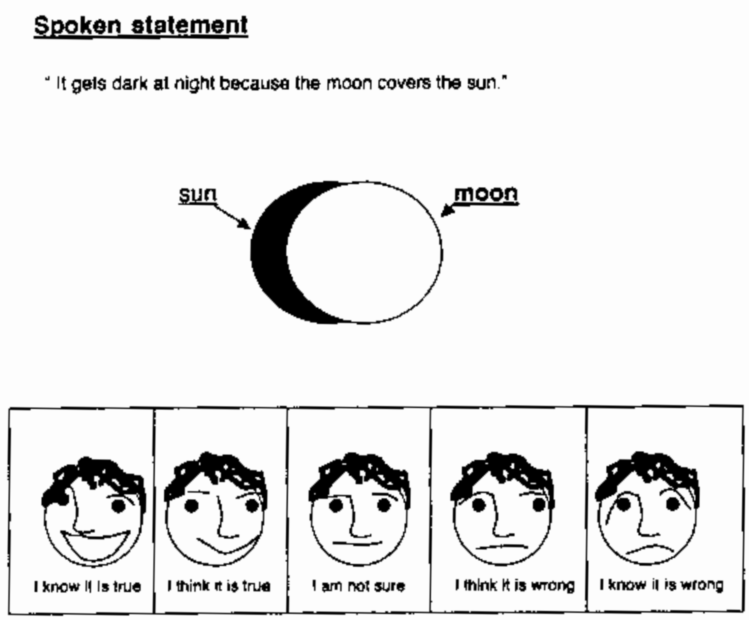

FIG. 7.2 Example of question in the survey instrument.

tronomy conceptual instrument for that particular domain. The commonly occurring notions are represented diagrammatically and are followed by prevalence diagrams showing the percentage frequency of pupils who hold these notions.

Planet Earth and Gravity. Children surveyed by interview and through the conceptual survey instrument were all presented with the same situation. They were asked to imagine that they had taken off from planet Earth in a space rocket and after they had been traveling away from Earth for a day they looked out of the window toward Earth. They were then asked to draw how they thought Earth would look.

After completing their drawing they were asked to draw in some people to show where they could live, then some clouds followed by showing rain falling from the clouds. As Fig. 7.3 shows, the drawings fell into four distinct notions and closely resemble those first proposed by Nussbaum (1979).

The first notion (common with younger children) represents planet Earth as a flat surface or saucer shaped, bearing a remarkable resemblance to the world view of the ancient Babylonians, Egyptians, and early Greeks (see Koestler, 1959). The older children almost always represented Earth as a sphere; however, it was common for them to draw in people and clouds on the "top half" or northern hemisphere only. A "prevalence diagram" shows

Notion 1

Earth shaped more like a saucer.

Notion 2

Earth sphere shaped but idea of up and down still persists. People only live on the upper half.

Notion 3

Earth sphere shaped. People living all over the surface but the idea of up and down still persists.

Notion 4

Correct view. People living all over the earth and 'down' towards the center of the earth.

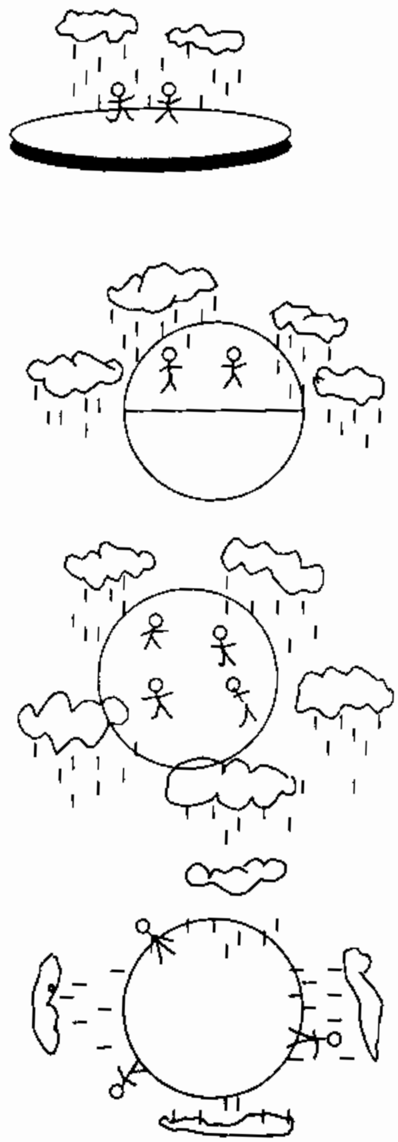

FIG. 7.3 Pupils' notions about planet Earth and gravity.

the percentage of pupils holding particular notions at certain ages (see Fig. 7.4). Notion 3 was the one most commonly held (the notion with the widest block). This representation shows a round Earth, with people living all over the surface, but with their heads facing the north pole; rain is shown falling "down" from the northern hemisphere. Very few children repre-

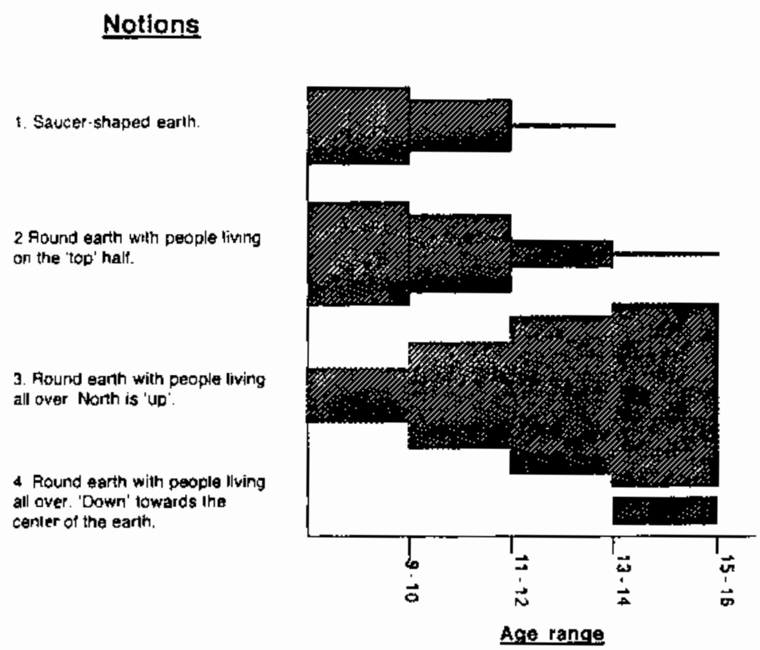

FIG. 7.4 The prevalence of pupils' notions about planet Earth and gravity.

sented planet Earth as a sphere with people living all over the surface, their feet pointing toward the center, and rain falling toward the center of the earth (see Fig. 7.3, notion 4).

Although, as the prevalence diagram Fig. 7.4 shows, a belief in the more naive notions of a saucer-shaped Earth or a round Earth with people living on the top half only declined with age, it is notable how few pupils—even in the older age ranges—subscribed to the accepted notion. This suggests that a Newtonian view of gravity does not feature in most pupils' thinking, an observation supported by the studies of Watts and Zylbersztajn (1981) and Preece (1985).

Day and Night. Interviewees were asked to explain why they thought it gets dark at night. They were able to explain their idea through drawings or by using polystyrene spheres. Their explanations gave rise to six distinct diagrams (see Fig. 7.5).

As with children's notions about planet Earth in space, a belief in the more naive notion of near and familiar objects causing the phenomenon declines with age, but the number of older pupils who explain day and night using a construct other than the earth spinning on its axes in front of a fixed sun is relatively high (see Fig. 7.6).

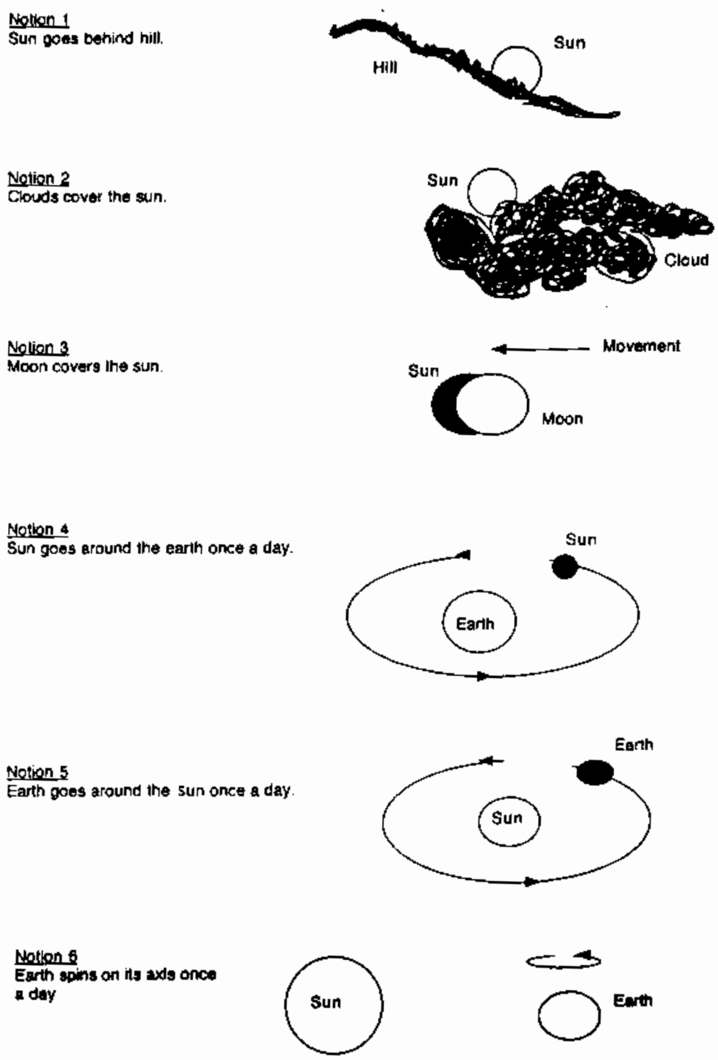

FIG. 7.5 Pupils' notions about day and night.

Phases of the Moon. All pupils interviewed were aware that the moon changes shape, but few were able to relate any patterns to these changes. The more naive explanations for the apparent changes in the moon's shape bore a resemblance to pupils' explanation for day and night, namely, that near and familiar objects were the cause of the phenomena (see Fig. 7.7).

As the percentage prevalence diagram shows, the most popular notion—

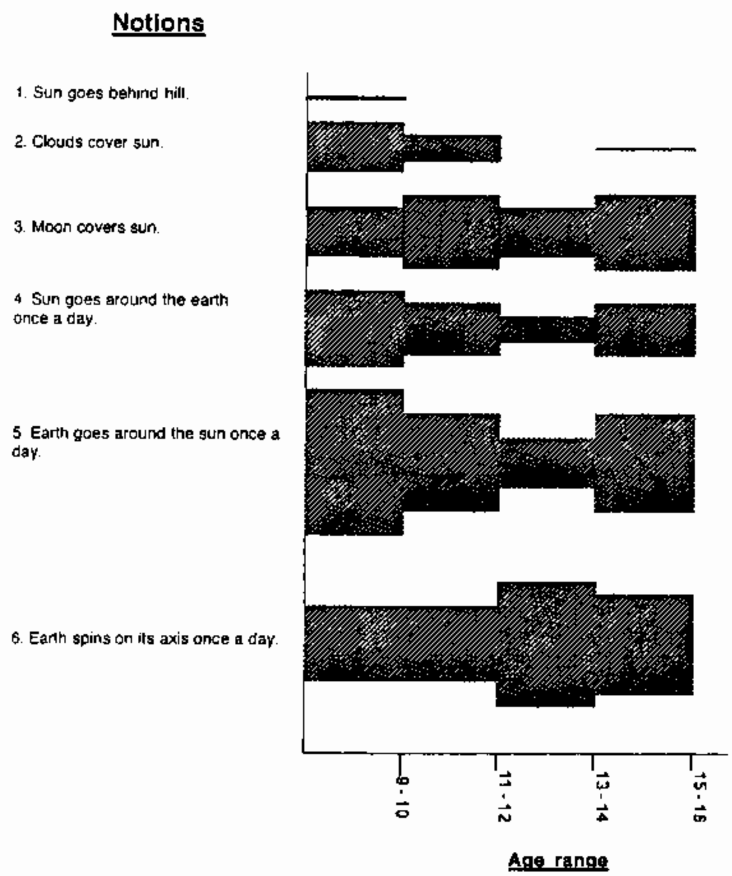

FIG. 7.6 The prevalence of pupils' notions about day and night.

and one that, increased with age—was of the earth casting its shadow on the moon, thus giving rise to its changes in shape (see Fig. 7.8).

The Seasons. Interviewees were asked to explain what caused it to be cold during the winter. Again pupils explained their ideas using drawings or polystyrene spheres. Their responses fell into six distinct notions, with the idea of the sun being further away during the winter the most popular explanation (see Fig. 7.9).

Once again, two notable features emerge from this survey, namely, that the younger children use near and familiar objects to explain the phenomenon, and a small percentage of older pupils explain the event by using the accepted notion (see Fig.7.10).

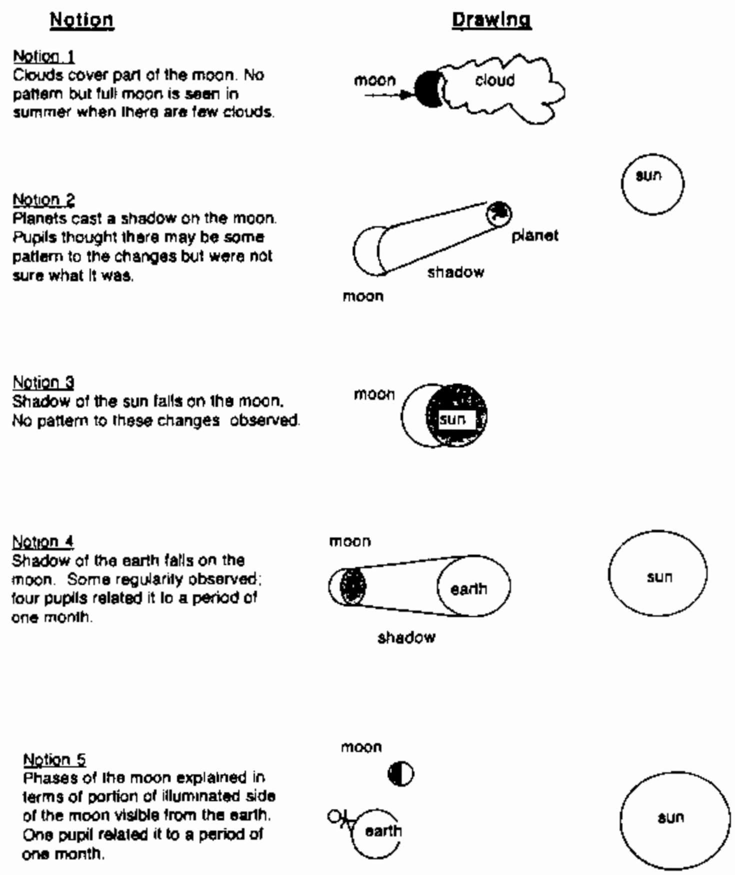

FIG. 7.7 Pupils' notions about the phases of the moon.

Discussion

Although the ideas children use to explain the easily observed astronomical events vary from one context to another, a number of conceptual developmental phases in the pupils' explanations can be identified. These phases are shown in Fig. 7.11.

The data from this research shows how children's early notions tend to be based on observable features of near and familiar objects; however, although these early notions tend to be used less frequently by older children, they are often exchanged for another alternative framework, one that involves a higher level of spatial awareness.

Although the results of this survey show a reduction in the more naive views as age increases, misconceptions still persist in many pupils up to 16

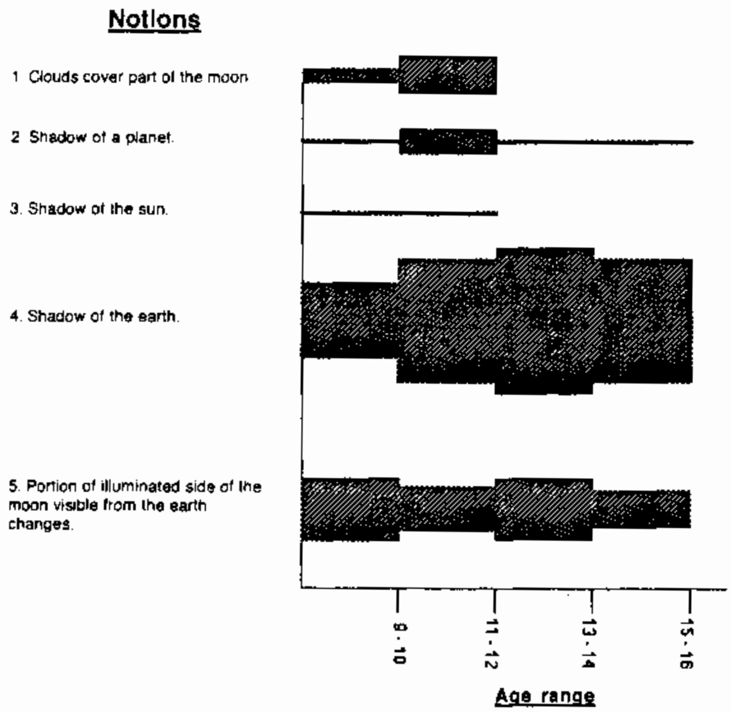

FIG. 7.8 The prevalence of pupils' notions about the phases of the moon.

years of age. This finding supports the claim that many alternative frameworks persist into adulthood, a view supported by the research of Durant et al. (1989), which indicated that a large proportion of the general public in Great Britain are confused about many scientific notions, including the motion of the earth around the sun.

It appears that misconceptions about basic astronomy are not peculiar to Great Britain; a survey carried out in France by Acker and Pecker (1988) showed that about 33% of the public still believed that the sun orbits the earth. Similarly naive notions have been observed in America by Sadler and Luzader (1988). Seemingly, medieval notions about planet Earth in space and a geocentric universe are alive and well in the way people construct their own explanations for basic astronomical events.

MISCONCEPTIONS ABOUT THE EARTH SCIENCES

Research into children's misconceptions about the earth sciences is less well documented than the misconceptions about astronomy. However, the

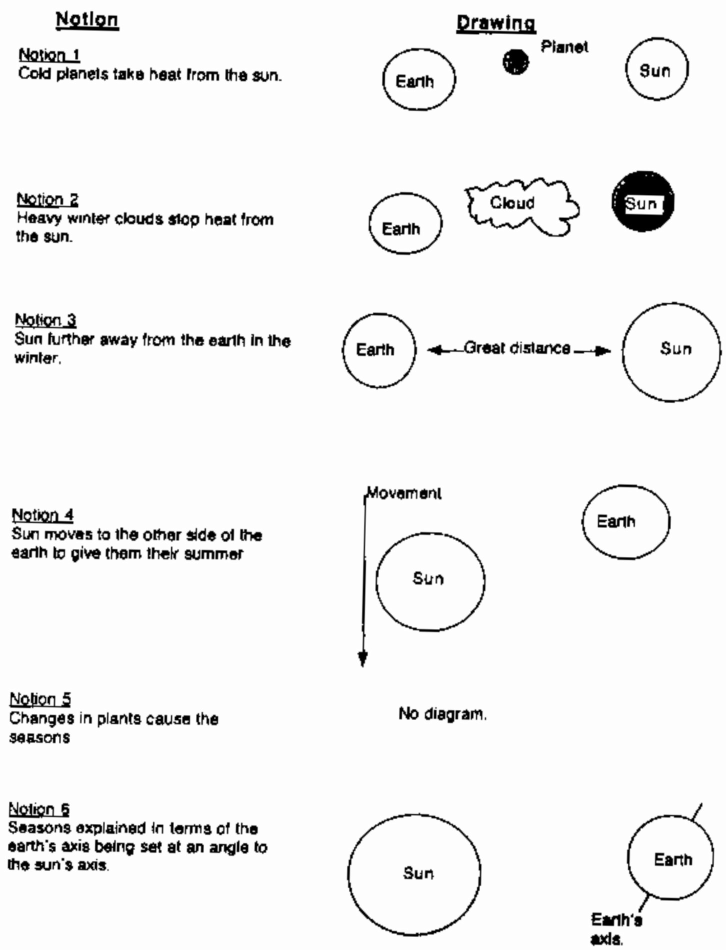

FIG. 7.9 Pupils' notions about the reasons for the seasons.

available literature demonstrates that—as with astronomy—pupils come into their lessons holding a number of misconceptions about our planet Earth. Philips (1991) reported on children who think that Earth is supported in space by resting on something, and that we live on the flat middle of the sphere. He went on to report about college students who think that all rivers flow "down" from north to south (consistent with the north being "up" notion mentioned earlier in this chapter).

Preliminary surveys carried out in Great Britain by the author support the findings of Phillips. It appears to be quite common for children to think that the inside of the earth is hollow and that it is possible to walk around

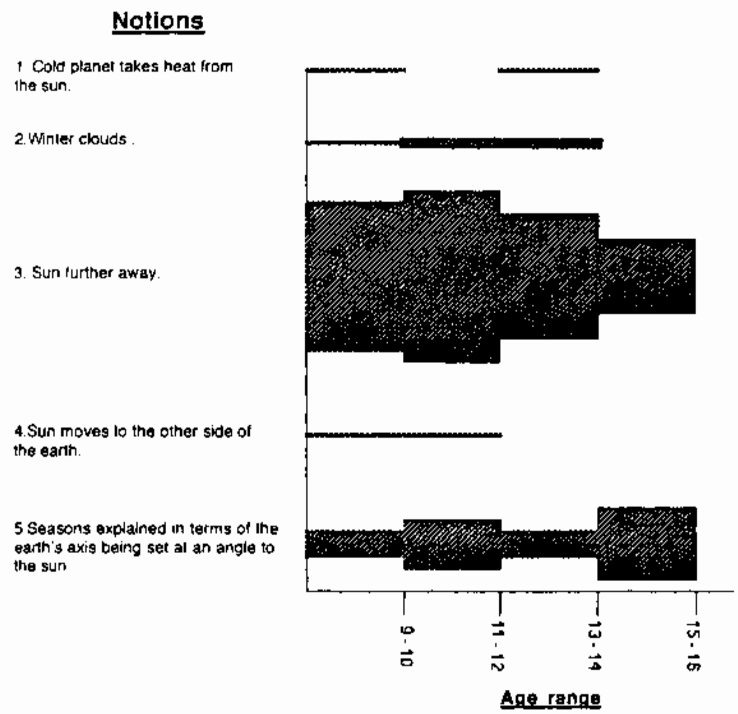

FIG. 7.10 The prevalence of pupils' notions about the reasons for the seasons.

quite freely inside the earth. Other children think that the earth is molten apart from a thin crust around the outside.

Children's ideas about the formation of mountains appear to offer a rich source of alternative notions. The following diagrams and explanations were obtained from a group of 11- to 12-year-old pupils in response to the question, "How do you think the mountains were formed?"

James claimed that in the beginning the Earth was flat like a smooth ball and that the streams eroded the valleys leaving the high ground as mountains (see Fig. 7.12). Ten percent of the 20 pupils taking part in these preliminary interviews subscribed to an idea similar to that given by James.

Nigel, along with 4% of the sample, thought that rocks falling from the sky formed the mountains (see Fig. 7.13).

Some pupils' explanations revealed a mix between science topics taught to them and their own explanations for the formation of the mountains. Steven combined his understanding of the water cycle—one of the topics recently studied during his science course—with his own explanation for the formation of the mountains (see Fig. 7.14). Ideas like Steven's offer a

Phase 1
Planet earth saucer-shaped and static. North 'up' and south 'down'. Changes in astral bodies caused by familar and near objects.

Phase 2
Earth round but commonly thought of as central and static. Naive notion of gravity still persists. Astral bodies can move to cause observed phenomena but their movement is represented as 'up', 'down', 'right' or 'left'.

Phase 3
The same naive notions about the earth and gravity still persist, but astral bodies are now seen to move in orbits. This orbital motion is seen as earth-centered.

Phase 4
The present heliocentric view and its associated gravitational ideas.

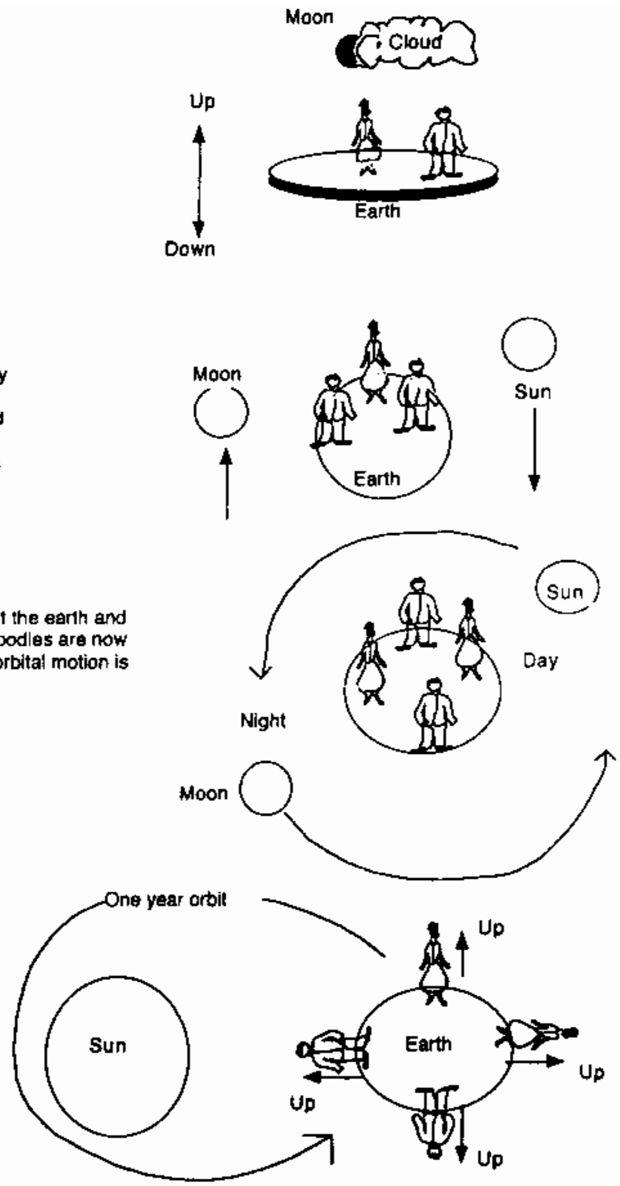

FIG. 7.11 **Phases in the conceptual representations that underlie pupils' explanations.**

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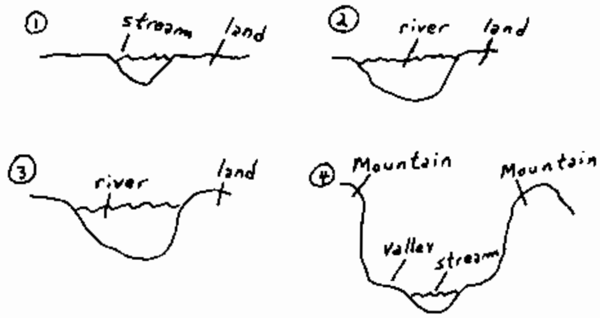


FIG. 7.12 James's explanation: "I think that planet Earth was once flat without mountains and streams eroded the land to make gullies and valleys."

FIG. 7.13 Nigel's explanation: "I reckon the mountains got there when rocks fell from the sky."

creative springboard for the design of experiments through which pupils can test their ideas.

USING ALTERNATIVE FRAMEWORKS IN THE CLASSROOM

During the early part of the 20th century, there was a growing recognition by educators that science is a practical activity; subsequently, there was an increase in the amount of practical laboratory work carried on during school science lessons. But the activities undertaken by pupils were little

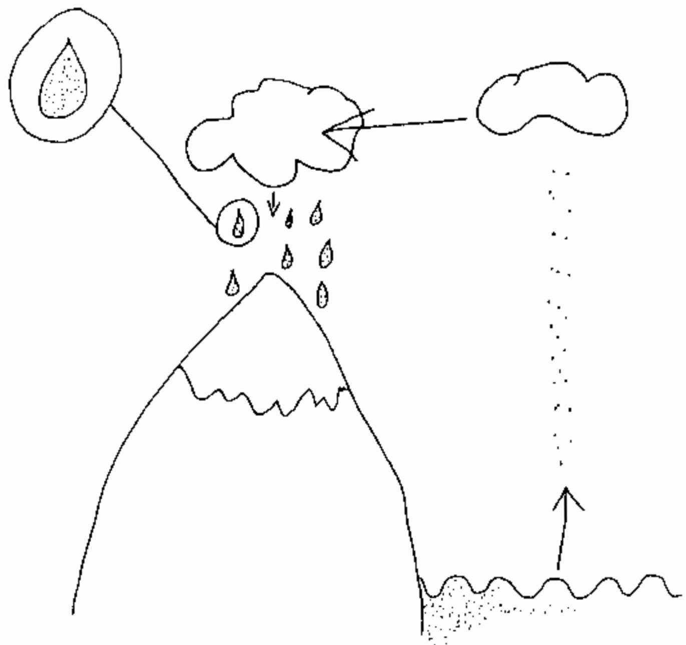


FIG. 7.14 Steven thought that as water evaporated from the sea to form clouds, tiny particles of rock, which had become dissolved in the sea, were lifted into the clouds along with the evaporated water. When the rain falls the particles of rock are returned to the land where they build up into mountain ranges.

more than routine exercises that had lost the educational value of real experiments and had evolved into arid, repetitive activities. The widespread introduction of general science during the 1930s led to the rejection of a great deal of this repetitive practical work, and by the 1960s the activities performed in school often had their roots in the common experiences of the children (Kerr, 1963).

Since the 1960s there has been a further increase in the amount of practical work carried on during science lessons, which is introduced to be illustrative or to provide confirmatory evidence for the presented theories (Driver, 1986). This strategy assumes either that children come into their lessons as empty pots and can be filled with the "right bits" of knowledge, or that they will discard their own ideas when presented with the accepted view by the teacher—a fact that Gilbert, Osbourne, and Fensham (1982) and Solomon (1983) showed does not necessarily happen. When science is presented in this way, children frequently form hybrid notions, a mix between their original ideas and those presented by the teacher, or the students function in two domains, that of their everyday experiences and that of the school laboratory, with different ideas in each domain.

The alternative conception movement offers a valuable and productive alternative, where many of the traditional illustrative or confirmatory "practicals" are replaced by activities that encourage pupils to put forward their own viewpoint and enable them to test alternative theories. If we accept the view that learning involves pupils in a process of conceptual change, then a knowledge of the initial conceptions they bring with them into lessons becomes important, as it provides a basis for the design of teaching materials that address these ideas. Such initial conceptions form a starting point from which pupils can test their ideas and modify them should they not hold good in the light of new evidence.

There are two levels at which the ACM can influence and enhance classroom practice:

Level 1. The teacher's awareness can be developed of the commonly occurring alternative frameworks for the particular topic being introduced. This can be achieved by including a summary chart of research data in the teachers' guide to a topic (see, e.g., Baxter & Sage, 1990). Teachers can then organize their teaching around the presentation of evidence to show that these commonly occurring alternative frameworks do not hold good when challenged.

Level 2. During a level 2 approach, pupils identify their own particular explanation for the topic being studied and then put their notion to the test to discover if it holds good, thus following the scientific process depicted in Fig. 7.15.

Using a Level 2 Approach to Challenge Pupils' Notions About the Seasons

The examples of pupils' responses given in this section were obtained from a group of average ability pupils attending a comprehensive school in the southwest of England. In this school astronomy is covered during two 35-minute periods for 6 weeks and forms a part of the modular science course.

During the early stages of the astronomy module, pupils are introduced

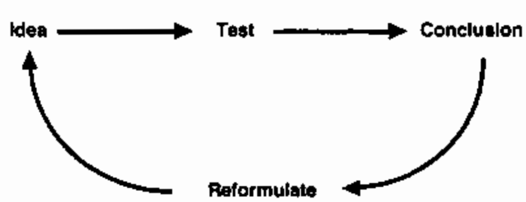


FIG. 7.15 The scientific process.

to the idea that scientific theories are always undergoing change. Examples are taken from early notions of planet Earth in space from a time when the most highly respected thinkers believed that the earth was saucer-shaped (see Draper, 1875/1970). With reference to examples from history, pupils are made to feel more comfortable about identifying and articulating their own notions when they discover that their ideas, although incorrect in the light of scientific advancement, were once popular views.

Examples of pupils' responses using a level 2 ACM approach were obtained during a typical lesson. The discussions with pupils were brief and more closely represent the discussions that take place during the course of a normal science lesson.

Pupils were first asked to draw and write about what they think causes the seasons to change. They did this in silence. Each pupil then made and used the model of the seasons (see Fig. 7.16) to challenge their ideas. If their original ideas did not hold good, they were asked to write about how they had to change their thinking.

As expected, most pupils thought that the earth moves away from the sun during the winter, although many of the other alternative frameworks reported in the first part of this chapter were identified too. For most pupils, the idea that the earth is slightly further away from the sun during the northern hemisphere winter was such a contradiction of their everyday sensory experience that it tended to dominate their discussions. The following short case studies of three pupils—Richard, Linda, and Anthony—make this point, and also demonstrate that conceptual change is often resisted.

Richard. In this interview the teacher (T) is asking Richard (R) about his work on the seasons. See Fig. 7.17 for Richard's diagram.

T: Richard, what did you say was the cause of the seasons; can you explain your drawing?

R: Well, it's this part of Earth facing the sun. When it is, it's summer.

T: OK., what about winter then?

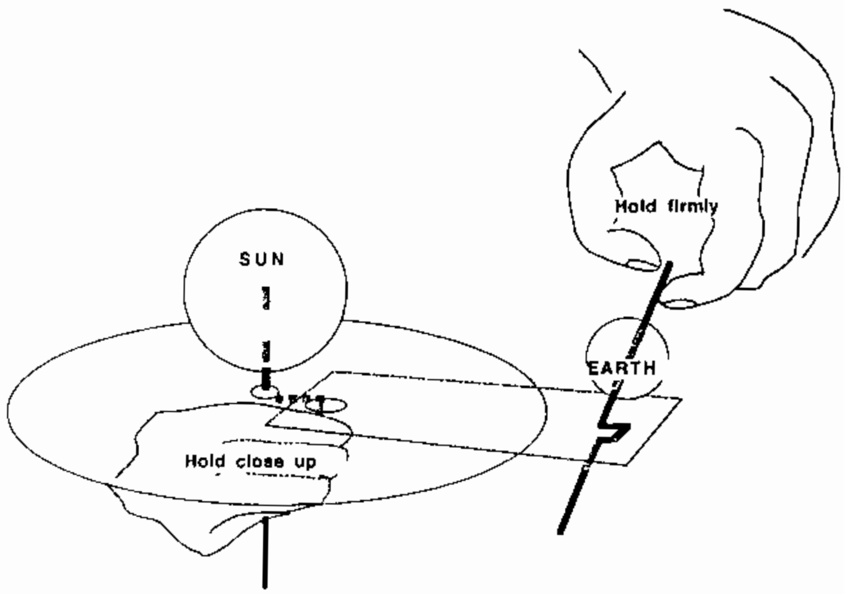
R: Well it's the same only this part [R points to the other side of Earth] that turns and they get summer.

T: Why do you think it's colder here? [T points to part of Earth not facing the sun.]

R: That's 'cause it's further away from the sun there.

T: Did you have to change your idea after using the model?

R: Yes. The nearer the sun is to the earth it's winter.



Using the model to solve the problem
Position the Earth so that it is as far away from the Sun as possible. Make sure that the angle of wire B is facing the Sun.

Holding the top of wire B in one hand and the bottom of wire A in the other, rotate the Earth around the Sun

What do you notice about the direction the North Pole is facing as the Earth orbits the Sun?.

FIG. 7.16 The model of the seasons.

T: But you have written something here about the angle of the earth's axis. Does it make any difference?

R: Yes, it turns us away in the winter when we are closer.

Richard, like many pupils, was so taken with this challenge to his own sensory experience about distance and heat, that he was unable to integrate information. Richard forgot about the cause of day and night (he had worked on this information previously and understood this). His diagram shows the earth taking 1 year to spin on its axis. This is a common feature of pupils' alternative frameworks on astronomy: One notion contradicts another.

Linda. Linda's diagram (see Fig. 7.18) is very similar to Richard's; it is difficult to see how she can explain both the seasons and the cause of day

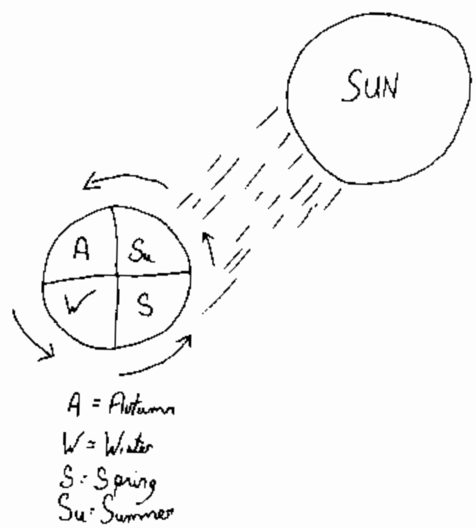


FIG. 7.17 Richard's ideas. Original explanation: "When part of the earth is facing the sun this is summer. The part of the earth furthest away is the winter. The parts that are left are spring and autumn. The parts are really quarters."

Idea change: "Angle of the earth to the sun. The nearer the sun is to the earth it is winter and vice versa."

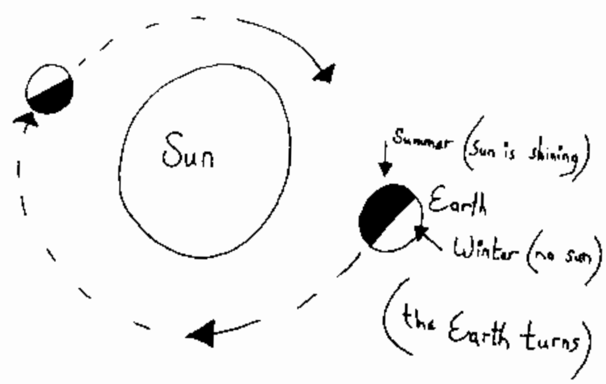


FIG. 7.18 Linda's ideas. **Original explanation:** "We get seasons because the earth orbits around the sun. When the earth is orbiting the sun it turns. The seasons are caused because the earth at times is not facing the sun (winter). Other times it is facing the sun (summer)."

Idea change: "The seasons are caused by the angle of the sun. Summer is when the earth is furthest from the sun. Winter is when the earth is closets to the sun but we are facing the opposite way to the sun."

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and night. After using the model, she places an emphasis on the earth being closer to the sun during the winter. She has also retained something of her original idea in as far as she still retains the "facing the opposite way" part of her explanation. Linda, like many pupils, will go to considerable lengths to interpret new evidence in a way that supports her original notions.

Anthony. Anthony is very protective about his original idea, claiming that he was "almost right." The part played by the moon in his first idea is clearly wrong, but he chooses to use the gentle phrase "I think I was wrong." He has either not noticed (which is unlikely, as their teacher circulated around the group drawing pupils' attention to the angle of the earth's axis) or refuses to acknowledge the importance of the angle of the earth's axis to the plane of its orbit. His attempts to protect his original idea are noticeable in the short interview carried out just after he had written about how his idea had changed. (Fig. 7.19).

T: Anthony, did you have to change your idea about the cause of the seasons?

A: Well a bit, but not much, I got it almost right.

T: What bit of your thinking did you have to change?

A: Well it was that bit about the moon . . . but I didn't say it was the reason, just it may be.

T: Use your model to show me how we get the different seasons.

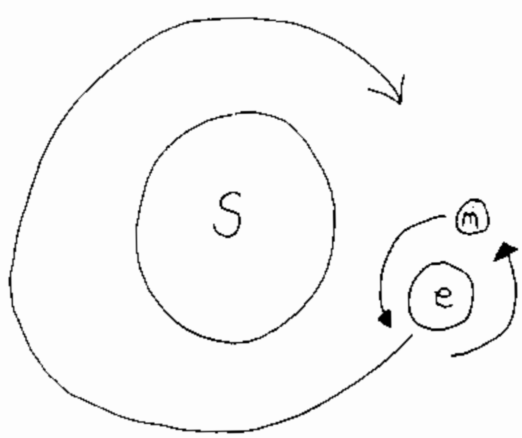

FIG. 7.19 Anthony's ideas. **Original explanation:** "The seasons change because we move around the sun, when that changes the weather from hot or to cold when we move around the sun. Or it probably gets colder if the moon gets in front of us as well."

Idea change: "My thinking was almost right, when I said the earth orbits the sun and the seasons change accordingly but I think I was wrong about the moon getting in between the earth and the sun."

A: [Picks up the model and orbits the earth around the sun.]Well it's like I said, the earth orbits the sun and we get the seasons.

T: Where will the earth be when it's winter north of the equator?

A: Places the earth in the correct position with the angle of inclination directed away from the sun.]It's winter now.

T: What's special about this position; what makes it winter?

A: The earth has gone around to here, and here is where winter is.

T: OK, what makes it winter here [takes model and moves earth to northern hemisphere summer position] and not here?

A: It can't be winter there cause we're facing the sun.

T: What makes us face the sun?

A: Well it's this angle here [points to the wire axis].

T: Can you now tell me how we get the seasons, but this time mention the angle.

A: We go around the sun like I said and we get winter here 'cause we're angled away from the sun. And when we get to there it's summer and we're facing the sun. This is where summer is and this is where winter is [he orbits the earth around the sun while saying this].

The evidence from these brief case studies suggests that pupils, like many scientists, attempt to interpret their results so that they support their original ideas. Those pupils who attempt to protect their original ideas appear to be faced with a crisis (like scientists during the demise of Ptolemaic cosmology), and like scientists appear to resist changes in theoretical structure (Donnelly, 1986). Paradigm shifts appear to be difficult experiences for both scientists and pupils.

Pupils' explanations for one astronomical phenomenon often are in contradiction with their explanations for another, related phenomenon. This fact can be put to good use by teachers. For example, after pupils have given their explanations for the cause of the seasons, they can be asked if their explanations will work in the light of what they know about the cause of day and night. For many pupils, this question will help them to revise updating their original explanations.

The results of this research show that when pupils revise their original notions, they may well pass through one or more stages before believing in the accepted view. Perhaps teachers should plan instructional sequences so that pupils can gradually move toward a theory without requiring them to reach clear-cut conclusions along the way (Nussbaum, 1989). Such an approach resembles how science has progressed in the past. For example, Herakleides of Portus (4 BC) proposed an intermediate model of our solar system in which Mercury and Venus orbited the sun, all three of which—according to his model—were in orbit around Earth (Koestler, 1959). Even the Copernican system was an intermediate model, later being revised to incorporate elliptical orbits. Progress in science is a stage-like process, often taking many years to change from one paradigm to another. Perhaps teachers are unrealistic in expecting pupils during one science lesson to make the same conceptual leaps that the world's finest scientists took years to achieve.

By adopting a teaching strategy in which our pupils are given an opportunity to challenge their own explanations, much of the astronomical ignorance that appears to pass into adulthood can be avoided. Pupils can emerge from their pre-Copernican world view just like the scientific community did. Teachers can symbolically recarve Flammarion's woodcut by helping pupils pull back their own sphere-like veil to catch a glimpse of the real universe that lies beyond their primary perception.

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What Research Says

Is There Gravity in Space?

By Varda Bar, Cary Sneider, and Nathalie Martimbeau

What are students' ideas about gravity beyond Earth's surface, and how can we create lessons that expand their conceptions of gravity? To find out, we started by asking some students what they think about why things fall. Following are the responses of two sixth-grade students—Raymond and Emily (the interviewer's questions are in italics).

Why does this pencil fall when you drop it?
R: Gravity is pulling it down.
E: Because of the gravity pulling it down.

Why does a cloud not fall?
R: It is very high in the atmosphere, and it is not touching the gravity.
E: It is higher in the sky. It is made of condensation of water. It does not fall because gravity does not reach it.

Why do the moon and sun not fall?
R: The moon is very high, past the Earth's atmosphere. The gravity stops at the top of the atmosphere. The same for the sun.
E: They are in space. There is no gravity there.

What is gravity?
R: It is the force that keeps us down. It is in the air.
E: It is a pull, a thing that keeps pushing things down on Earth or a planet. Air is around the Earth and keeps gravity. The atmosphere keeps the gravity inside.

Students' Ideas

Raymond's and Emily's ideas are not unusual for students their age. Several studies have shown that a majority of children and many adults are under the impression that air either creates gravity or is necessary to transmit gravity to falling objects (Gunstone and White, 1980; Riggiero et al., 1985; Watts, 1982).

Bar (1994) has recently extended this research through interviews with over 400 Israeli children, ages 4–13. Bar found that the most common ideas expressed by children ages five to seven are that things fall because "they are not held," or the sun and moon do not fall because "they are glued to the sky." A frequent response of seven- to nine-year-old students is that things fall because they are heavy: "Clouds are light and not heavy and do not fall." Students ages 9–13 expressed the idea that things fall because of Earth's gravity. But most students believe that air is necessary for gravity, as exemplified by the interviews with Raymond and Emily. Other research indicates that this belief persists into high school (van Zee and Minstrell, 1997).

Our Learning Experiment

We wanted to go beyond this research to find out what we could do to help students understand that gravity can act beyond the Earth's atmosphere and to gain a more adequate intuitive understanding of how natural and artificial satellites stay in orbit. So, we conducted a mini-study in two sixth-grade classrooms. With the help of Phoebe Tanner, a science teacher at Martin Luther King Jr. Middle School in Berkeley, California, we selected two classes, one with 23 students and the other with 25 students.

The students had studied the solar system earlier in the year and did not seem to be confused about the idea that moons traveled in orbits, since they were quite familiar with orbits from television shows like *Star Trek*. But, when we interviewed five students from each of the two classes, we found that their ideas were very similar to those of the Israeli children of the same age range. Eight out of 10 students expressed the idea that gravity must have air to act—they did not understand the role of gravity in keeping planets and satellites in their orbits.

We devised a lesson that would help the students understand that gravity acts beyond Earth's atmosphere. Two weeks after we interviewed the sample of 10 students, we presented this lesson to both classes during two consecutive 45-minute time periods (with a break between the time periods). We measured how much the students learned from the lesson by interviewing the same 10 students about a week after the lesson. To find out what the others learned, we also asked all of the students to answer a set of written questions at the beginning and the end of the activity.

The Lesson Plan

To figure out how to teach students that gravity acts beyond the atmosphere, we asked ourselves how scientists learned about it in the past. When Copernicus proposed his idea of a sun-centered system in 1543, he had no idea what force might keep planets and moons in their orbits. Even in 1609, when Galileo supported Copernicus's ideas with his observations of Jupiter's moons, a full description of gravity was far in the future. But Galileo had begun experiments in the laboratory that eventually led to Newton's full description of gravity in the next century.

Most people know about Galileo's experiments with balls rolling along inclined planes, but his experiments with cannonballs led us to a successful lesson. While we weren't prepared to bring cannons into the classroom, we thought that large, white plastic or rubber balls would be a good substitute. Little by little, we led the students to recognize that the same laws that governed how things move on Earth also govern how the moon, Earth, and other planets move through space—even though there is no air up there!

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First Activity: What Will Happen to the Ball? The students were asked to draw what they think will happen to a ball after it rolls off the edge of a table—first when it's rolling slowly, then when it's rolling quickly. Working in groups, the students discussed their ideas and made predictions.

Then, the teacher led a class discussion to identify different ideas of what might happen. Students were invited to come up to the chalkboard, one at a time, and draw what they saw—only if their idea was different from ideas already presented.

The teacher led a discussion about the predictions and emphasized that the students should vote for what they thought would really happen, not for who drew the idea on the board. Also, the students could change their minds if someone had a convincing argument. Then each student chose the prediction he or she felt was correct. The teacher indicated each student's choice on the chalkboard.

Working in groups of three or four, the students tested the various predictions. They took turns rolling the ball off the table, while the others observed it. Students conducted the experiment with different speeds of rolling and discussed the results in light of the different predictions on the board. The students concluded that the ball's trajectory had a parabolic shape (they did not use this term, but pointed at the "correct" drawing). They also concluded that "the faster the ball moved, the farther it fell."

When the students finished their experiments, the teacher assembled them around the chalkboard to discuss their experiments and to vote

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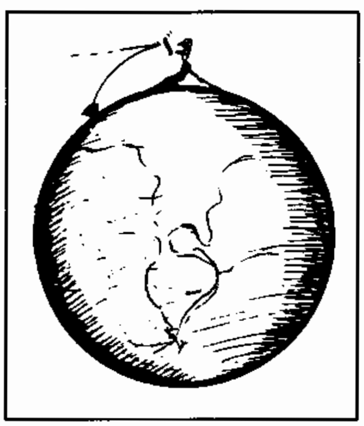
again. This time there was much broader agreement about how the ball would move, with most voting for the classical shape of a trajectory.

At this point, the students were able to draw and describe what happens to a ball moving forward when it falls under the force of gravity. Although they may not have been able to clearly articulate this condition, the students could see that it was repeatable. They also noticed that when the ball was rolled faster, it went farther out from the edge of the table before hitting the floor, but the general shape of the curve remained the same. Many students remarked, "The ball doesn't go straight down, near the end—it keeps going away from the table as it falls."

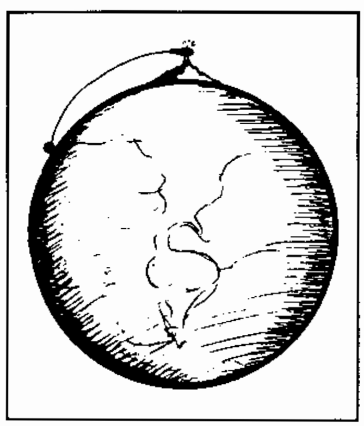
At the end of the session, the students were asked to explain why the ball follows this path. The students had no difficulty in explaining that the motion resulted from the forward push on the ball when it was rolled and the downward force of gravity.

Second Activity: From Baseballs to Earth Satellites. To begin the next activity, the students viewed a series of overhead transparencies as the teacher led a question-and-answer session, in the tradition of Socrates. (See the sequence of transparencies below.) The first transparency shows the Earth with an enlarged mountain. The teacher told the students that the mountain was very high and that most of the atmosphere was below the mountain top.

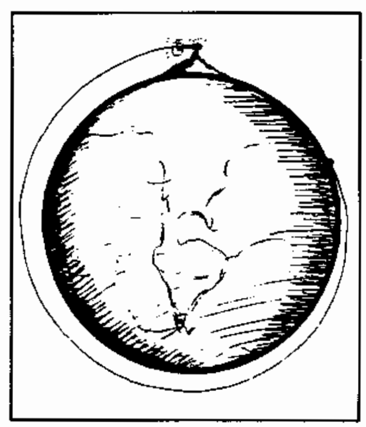
In the transparency, the drawing depicts a baseball player hitting a ball pitched from somewhere in space. The ball follows the trajectory that the students had observed in class. The teacher asked the students what would happen if the ball were hit harder. ("It will go farther around the Earth.") The teacher replaced the transparency of the baseball player with a transparency of a cannon, which could project the ball faster. Students saw that the ball went farther around the Earth. Subsequent transparencies showed the ball being blown out of the cannon with more and more force. Each time, the students were asked to determine what forces made the ball's path take that shape and to predict what would hap-



Transparency 1. *A picture of the Earth with an enlarged mountain shows a baseball player hitting a ball pitched from space. The ball follows the trajectory that the students had observed in class. The students are asked, "Why doesn't the ball go off into space?"* (Because gravity pulls it to the Earth.) *"What would happen if the ball is hit harder?"* (It will go farther.)



Transparency 2. *The baseball player is replaced by a cannon, which could project the ball faster. Students see that it does go farther. They are asked, "Why doesn't the ball go off into space?"* (Because gravity pulls it into a curve.) *"What will happen to the ball if we use a double charge in the cannon?"* (It will go farther.)



Transparency 3. *The students see that the baseball goes farther. The teacher asks the students, "Why does the baseball follow the curve of the Earth?"* (Gravity pulls it.) *"What will happen if we use a triple charge in the cannon?"* (It will go around and hit the cannon or go into orbit.)

pen if the force of the cannon was even greater. After the third frame, many of the students predicted that the baseball would go into orbit.

Next, the teacher showed the students a picture of the space shuttle and asked what forces make it go into orbit. The students were able to recall what they had seen on television or in the movies, and explained how rockets—acting first upward, then at an angle—thrust the shuttle into space and how gravity kept it moving in its orbit, just like the baseball. The teacher asked, "What would happen to the shuttle if we could somehow turn off Earth's gravity? ("It would fly off into space!") The teacher reinforced the students' explanations, stating that even in space—where there is no air—the gravitational attraction of the Earth keeps pulling the shuttle into its orbit. Using the last transparency, the teacher led a similar discussion about the Earth's moon.

Closure: How Do Jupiter's Moons Stay in Orbit? With the overhead projector off, the teacher asked the students the following questions:

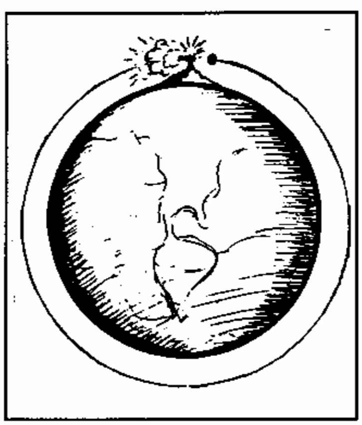
- "How do you think Jupiter's moons got their forward movement in the first place?" ("Maybe they were asteroids moving through space.")
- "What keeps the moons moving in circles and not flying off into space?" ("Gravity.")
- "Does that gravity come from Earth?" ("No, from Jupiter.")

One of the students asked if the moons themselves also had gravity. After asking the other students to respond to that question, the teacher was delighted to confirm that, "Yes, not only does Jupiter pull on its moons, but each of the moons also pulls back, keeping the moons in their orbits."

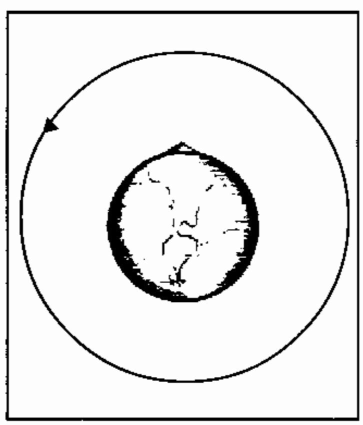
The teacher ended the gravity lesson by explaining that in only two 45-minute periods, the students were able to trace the development of ideas that took 200 years for scientists to discover.

Did the Students Learn?

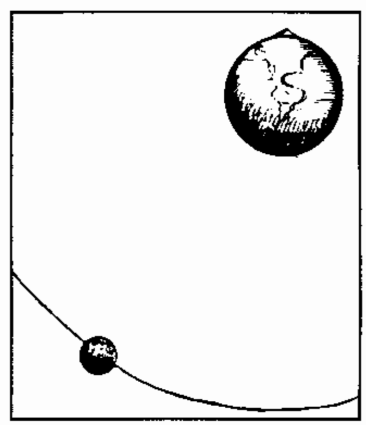
To find out whether students changed their ideas about whether or not there could be gravity in outer space, we compared their answers to the written questions presented before and



Transparency 4. *The students see that if we don't get the cannon out of the way, the baseball will go all the way around the Earth and hit it. If the ball is not slowed by the air, it will go around and around the Earth. The ball then becomes a satellite of the Earth.*



Transparency 5. *The teacher asks the students, "What does this show?"* (Space shuttle in orbit around Earth.) *"What keeps it in orbit?"* (Gravity.) *"Is there air out there, where the space shuttle is?"* (No. Gravity acts anyway.)



Transparency 6. *The teacher leads a similar discussion about Earth's moon. "What does this show?"* (The moon in orbit around Earth.) *"What keeps it in orbit?"* (Gravity.) *"Is there air out there, where the moon is?"* (No. Gravity acts anyway.)

Resources for Teachers

- Great Explorations in Math and Science (GEMS) is a curriculum series that provides a variety of hands-on activities, including several on astronomy. We recommend the teachers' guides *Earth, Moon, and Stars* and *The Moons of Jupiter*, available from Lawrence Hall of Science, University of California, Berkeley, CA 94720-5200.
- NASA provides a wide variety of free films, videos, and slides about astronauts in space. Contact your local NASA Teacher Resource Center or visit the NASA home page on the World Wide Web at http://www.nasa.gov.
- *Astronomy Village* (for MacIntosh users) is a comprehensive software program that enables middle and high school students to conduct astronomical research. It includes an orbit simulator. The program is made available through NASA Teacher Resource Centers.
- ORBITS (for IBM-compatible computers) is an excellent software program about the solar system. Available from Software Marketing Corporation, 98312 S. 51st St., C-113, Phoenix, AZ 85044.
- *The Universe at Your Fingertips* is a collection of 100 of the best activities in astronomy, selected by a team of teachers, available from the Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112; (415) 337-1100; fax (415) 337-5205.

Table 1.
"Does gravity act in space where there is no air?"

	Pre-Test	Post-Test
Yes	13	23
No	31	10
Not Much	0	3
Only Near Planets	0	4
No Answer/ I Don't Know	4	8

after the activity. The key question was, "Does gravity act in space where there is no air? Why or why not?" We classified the students' answers to this question, which are summarized in Table 1.

From the table, we can see that on the pre-test, about two-thirds of the students gave the definite answer, "No, gravity does not act in space where there is no air." Based on preliminary work with many other children in other countries and on the interviews we conducted with 10 of these students before this activity, this was not surprising.

On the post-test, there were more than twice as many "Yes" answers than "No" answers. We have some confidence that students were giving us their honest opinions because during the activity, we encouraged them to be "good scientists" and to stick by their personal opinions even if they differed from what other people thought.

The post-tests revealed that, by the end of the activity, not all of the students were convinced of the value of Newtonian logic. Ten students still believed that gravity does not act in space, while 15 students gave a variety of other answers, including some in the "I don't know" category. This suggests that, for many students, conceptual change was beginning to occur but the students had not yet consolidated their ideas about gravity.

These results were confirmed by the interviews that we conducted one week after the activity with the same 10 students whom we interviewed before the activity. During this second round of interviewing, participants were asked if gravity could act in space without air. In general, we could classify these students into three groups.

One group gave convincing reasons why gravity acts through space: "Since the Earth keeps the moon in orbit, there must be gravity in space," or "This is why the planets go around the sun."

A second group of students was still unconvinced that gravity could act in space, where there is no air, but their answers were not consistent. For example, some said that there must be gravity near the moon (where there is no air) or that the moon stays in its orbit because it is within reach of Earth's gravity.

The third group of students showed very little change. They internalized the first part of the activity, which concerned the rolling balls, but did not generalize it to include the notion of satellites around the Earth. However, even achieving this goal is a step in the right direction since, as we learn from the history of science, changing ideas about how things move here on Earth is the first step in learning about how things move in space.

Changing Misconceptions

We all know that it is hard for students to change ideas about the world that they have learned through a lifetime of experiences and to explain events in a way that is perfectly satisfactory to them. The students' ideas "work" for them, but these ideas are quite different from what scientists have in mind when they speak of subjects such as orbits and weightlessness.

To understand gravity in space, students need to crystallize their ideas about how things fall on Earth, then apply these ideas.

For this reason, we were not discouraged when we found that only some of our students were able to gain a more adequate understanding of how moons and space satellites stay in orbit.

For factual information or simpler concepts, we might expect closer to 100 percent success; however, for the development of fundamental concepts like gravity, we have to be more patient and expect that more such experiences—over a longer period of time—will be necessary to reach all of our students.

Thanks to the students at Martin Luther King Jr. Middle School, we have learned that many students can change their ideas about the relationship between gravity and the air. Simply telling the students that this is so will probably not work. As we have discussed, students need to crystallize their ideas about how things fall on Earth, then apply these ideas—first in the classroom, and then to more distant objects until they achieve a general understanding of gravity.

As a follow-up to this activity, the students can conduct experiments using a vacuum pump and actually experience the fact that gravity, as well as magnetic attraction or electrostatic attraction, can act even without air. Such hands-on experiences may help in creating a cognitive conflict among students who may not yet be convinced that gravity can act in the absence of air.

Resources

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