Sc	I	Es	N	Ce
Scandium	Iodine	Einsteinium	Nitrogen	Cerium

Ra	O	C	K	S
Radium	Oxygen	Carbon	Potassium	Sulfur

Montessori
Geoscience Lessons and Activities for the E-II Classroom

by

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Lessons and Follow-Ups with Concepts from

Physical Science, Earth Science, & Engineering Technology

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A few select lessons are included to give you a glimpse of what

What's-a-Matter?

Matter vs. Energy, Conservation of Matter and Energy

Prerequisite Knowledge/Skills:
No specific prior experience needed. Children have likely done some experiments on properties of matter such as states of matter, sinking and floating and the like. From these they have internalized some principles but may have no terminology to associate with it.

Isolated Difficulties:
The Universe is made up of Matter and Energy.

> *Note: this is a classification system that was universally accepted (no pun intended) until fairly recently. There are theories emerging that suggest that matter is, in essence, a very slowly moving form of energy: https://www.sciencealert.com/physicists-suggest-energy-fragments-is-the-best-way-to-describe-matter. This lesson does not attempt to address this new concept.*

Law of Conservation of Matter.

New vocabulary: matter, energy, Conservation of Matter

Direct Aim: Students will
- classify familiar aspects of everyday life dichotomously, as matter or energy
- use the definition of matter to test whether something is matter or energy
- understand that matter can be rearranged but not created nor destroyed

Indirect Aim: Students will
- practice using scientific definitions as a system of classifying substances

Applicable Next Generation Science Standards:
2-PS1.A: Different kinds of matter exist and many of them can be either solid or liquid, depending on temperature. Matter can be described and classified by its observable properties. ... A great variety of objects can be built up from a small set of pieces.
5-PS1.A: ...The amount (weight) of matter is conserved when it changes form, even in transitions in which it seems to vanish. …

<u>Preparation</u>: Confirm that children were introduced to states of matter in lower elementary
Prepare the provided tickets that follow the lesson.
Gather the following materials:

test tube in a stand or flask with a tightly fitting, single-hole rubber stopper.
clear or opaque funnel tightly fitted through the rubber stopper.
one liter soda bottle with a few inches of colored water in the bottom
bucket for discarded water
bread or crackers and an edible spread (for the sake of the write-up, we will use jelly)
knife & plate
plastic sandwich bag (zip-loc ® works best)
brown paper bag
hammer

<u>Connecting to Prior Knowledge:</u>
1. Last time, we defined science as a way to explain observations of the physical world and to ask the Universe, “How do you work?” Invite the children to share any examples they have of how

they have been scientists or engineers since the last lesson. (Be ready with examples of your own in case they are initially stumped.)

2. Tell the children that since they have already studied many aspects of the known Universe in lower elementary, today they are, as a class, going to list everything in the Universe. Feigning surprise, ask, "Does that seem like a big job? Well, we'd better get started! Who can name something in the Universe?" Get the children on a good roll. In each case, as they name things, agree, "Yes, that is *stuff* in the Universe!"

New Learning:

3. Express the opinion that *stuff* seems to cover everything that has been mentioned so far. But *stuff* is not a very dignified and important sounding word, the kind of word that scientists like to use. Scientists use a word that means *stuff*: MATTER. Lay out the corresponding ticket.

4. Matter is defined as anything that occupies space and has weight. Ask several children to bring some matter to the line. For each item, ask the child if the item has weight. Show that the matter occupies space (passes the noun test) by trying to place it where a previous sample of matter is sitting; this can't be done without moving the previous sample of matter. Two bits of matter cannot occupy the same space.

5. What about light? Is light matter?

   Children may conclude that light does not occupy space and therefore it is not matter, but it is more likely that this will inspire some conversation. Children may point out that light can be blocked, as in a shadow, and assert that light, therefore, occupies space. If they make this assertion, they are doing some great thinking! Invite a volunteer to box up some light and move it to another location. (Of course, that can't be done – so what does that mean?)

   Light moves through space, and while it can be deflected by objects, it does not occupy the space through which it moves. Neither does it have weight. (At least not as we understand *weight*. Adults who are interested in the concept of mass and energy existing together and producing a weight-like force might Google "How much does light weigh?" or go to https://science.howstuffworks.com/light-weigh.htm)

   Ask about heat and sound. None of these occupy space or have weight. Tell the children that light, heat, and sound are all types of ENERGY. Lay out the corresponding ticket.

   Energy is the ability to do things or make things happen. Heat warms things. Sound waves enable us to hear things happening. Light shines on or through objects, giving them color and enabling us to see them. Write out the word. "With these two terms, MATTER and ENERGY, we can describe everything in the universe!"

6. Divide the class into two teams: MATTER or ENERGY. Tell them that you will call out a number of words. Ask each team to stand if they hear a word that they think belongs on their team (i.e. the Matter team would stand when the teacher says "paper", the ENERGY team would stand for "light".) Call out the following words in relatively close succession:

table	people
sunshine	heat
trees	music
air	

It is probable that a discussion will ensue over which category best describes air. Allow the discussion to go until most children have taken a stand one way or another. Vote if necessary. "This is your *hypothesis*." Let's test the hypothesis!

7. Create a "lab report" in a visible space, like on a large white board:

   Question: Is air matter or energy?
   Background Research: Matter occupies space and has weight. Energy has the capacity to do things or make things happen.
   Hypothesis: Air is _____. (Capture the majority vote).
   Materials & Method: Using a funnel, rubber stopper, flask, water, and bucket, see if air occupies space.

8. Show the funnel in the rubber stopper. Hold it OVER the test tube or flask. Ask the children what will happen if you pour water into the funnel. Demonstrate this and take observations. *Water flows through.* Empty the test tube or flask, fit the funnel into the stopper and the stopper into the flask and repeat the process. Again, take observations. *Water is held out of the test tube or flask. Often (but not always), after a minute, a small amount drops from the funnel. If that happens, this phenomenon will repeat every so often until the funnel is empty.* Record observations on the lab report.

   Ask the children to explain this phenomenon. Take all ideas. Guide as necessary to this explanation:

   > *When the stopper is placed in the test tube or flask, the only way for air to escape is through the funnel. When water is poured into the funnel, initially, water is kept out of the test tube or flask by air, as AIR OCCUPIES SPACE.*
   > *Because water is heavier than air, it pushes down on the air, sometimes firmly enough to squeezes through the water in the form of a bubble. At that moment some water drips into the test tube or flask.*

9. Ask the children to answer the question posed by the experiment. Record their response on the lab report:
   Conclusion: Air is matter

10. Tell the children that you are going to create matter before their very eyes. Make a jelly sandwich* and assert that you have created matter! Hopefully, the children will object! You did not make matter, but simply rearranged it. *While a sandwich was created, it was made from jelly and bread, which, in turn came from fruit and grain, which in turn came from plants, which in turn came from seeds, which in turn came from plants...*

11. Announce that since you cannot create new matter, perhaps you can destroy old matter. Place the sandwich in a plastic bag, squeeze out the air, and seal the bag. Place the plastic bag into the brown paper bag so the sandwich is no longer visible. Hit it several times with the hammer. Peak inside. "Wait! There's still matter in there!" Hit the sandwich several more times. Peak inside. "It's smaller, but it's still matter!" Once again, hit the sandwich a few times. Peak inside. Feigning covertness, crumple the bag, wad the sandwich into a ball and hide it. Announce triumphantly, "There! It's gone! I have destroyed matter!" When the children tell you that the sandwich is not destroyed, admit that you have failed to create or destroy matter. Even if the bag were burned, ashes would remain. Even if the sandwich were eaten, it would have been converted to muscle, bone, organ and fat tissue, and waste.

**If your classroom is populated by children who experience food scarcity, consider giving each child crackers and jelly prior to the lesson, retaining one cracker and jelly for your experiment.*

12. Explain that there has been a law, ever since the Big Bang, that matter can be neither created nor destroyed. It is called the Law of Conservation of Matter. Write "The Law of Conservation of Matter" on paper or on a board.

13. Ask children to recall an experiment from lower elementary, in which an ice cube was heated up in a pan. *Children will hopefully remember that the ice cube melted and eventually the water boiled off.*
    Ask if anyone can recall the names of the three states of matter. Lay out the heading tickets from Set B: *solid, liquid, and gas.* Invite discussion about the three states of matter. Ask 3rd period questions like,
    Which of these expands to fill its container? *(gas)*
    Which of these keeps its shape (unless broken)? *(solid)*
    Which of these takes the shape of its container (at least the bottom portion of it!) *(liquid)*

14. Describe children's follow-up options.

<u>Follow-up options (choose one or mix and match):</u>

Record Knowledge:

- Repeat the experiment, creating their own lab report or using the form provided with the first lesson in this album. This is a gentle introduction to The Scientific Method with an experiment that is not 100% guaranteed success. If the stopper is not properly seated, the water will pour through the funnel. If additional challenge is desired, replace the stopper with clay. Again, the children will need to create a tight seal with the clay. Once they are successful with this, it can be interesting to poke a very small hole in the clay with a pin, creating a small tunnel from inside the flask to outside the flask. Once the hole is large enough to permit a stream of air to escape, the water will flow gently from the funnel into the beaker.
  Doing this as the first experiment ensures that the children do not have to achieve unknown results or draw their own conclusions at this point.

Demonstrate Comprehension/Application:

- Children can work with Card Set A individually or with a partner, sorting cards into 2 columns: matter and energy. The cards require more focus than the game during the lesson because they are matter and energy pairs. There is a cause-and-effect relationship between each pair (e.g. sound comes out of a horn).
  "Working with Card Set A" can mean simply sorting each pair of words into the two columns, recording the result in their science notebook. For a cross-curricular application, invite children to write a vivid sentence for each matter-energy pair (e.g. When the camp counselors lit the firewood ablaze, the heat warmed our frozen faces.) For extra challenge, tie them all into a cohesive story!
- Children can team with 1 or 2 friends to work with Card Set B, sorting cards into 3 categories: solid, liquid, and gas. This work is more challenging than it might first appear. Children will need to organize the cards by theme and by state of matter. For example, one set of three cards pertains to states of matter for water. Another pertains to states of matter for earth materials. One is elements from the periodic table. And one theme is things that go into our bodies. Within each theme, there is a solid, a liquid, and a gas. Some of this may require a bit of research (e.g. which

of the three elements is a solid, liquid, or gas at room temperature). Working with this card set is guaranteed to create conversation!

Application:

- Children can team up with one or two friends to work with card set C, matching the process of changing from one state of matter to another with the vocabulary word that names the change in state. Some of these (particularly sublimation) will likely be matched up by process of elimination. Once they have correctly identified all of the vocabulary, they can write a paragraph that uses all of the vocabulary words. This could be an expository paragraph, or it could be a narrative entitled "My Life as a Water Droplet" or "An H_2O Molecule's Story".

Synthesis:

Challenge students find another way to demonstrate that air is matter, using any of the supplies from the lesson and a balloon.

One way to demonstrate this is quite simple: inflate the balloon! The air is occupying the space inside the balloon.

Another way to demonstrate this uses a balloon and the 1-liter soda bottle.

- *Feed the balloon through the opening of the soda bottle – but hold on to the opening of the balloon!*
- *Stretch the opening of the balloon over the opening of the soda bottle, sealing the bottle.*
- *Blow hard into the balloon. It will not inflate because the air in the soda bottle is already occupying the space inside the bottle – there is no room for the balloon to expand.*

Extension: This can be offered as an extension to this lesson and/or can be added to a running list of possible ideas for personal interest work for throughout the year.

Sometimes when matter changes state, it can seem that some of the matter appears or disappears! We have seen this with boiling water changing to water vapor – the water just seems to disappear, but it doesn't. Here are a few other examples:

- When you bake bread or a cake, the loaf of bread or the cake grows in the oven, as if matter were being created.
- When you mix sugar into water, the sugar disappears
- When you observe a chunk of dry ice sitting on a surface, the dry ice seems to gradually vanish.

Challenge students to think of a way to explain how these changes occur without creating or destroying matter. Can they design an experiment to try to prove their explanation?

Proof often takes the form of weighing the substance before and after the process. For example:

- *a cake weighs the same whether it has been baked or not. The added volume is air bubbles that expand with heat, causing the batter to expand. Weighing the cake before and after will show that no matter was created. (There will be a negligible weight loss due to water evaporation.)*
- *Weighing the sugar and water before and after mixing them will similarly show that the sugar doesn't disappear – it just dissolves. (And the volume in the cup will increase as well.)*

The dry ice sublimates directly to gaseous CO_2. That can be shown by dropping a small chunk of dry ice into a beaker and covering the top of the beaker with the opening of a balloon. As gaseous CO_2 is released, the balloon will inflate.

Note: once an experiment is designed, it is most satisfying if the student gets to conduct the experiment. Some of these (like the experiment with dry ice) may result in an experiment that requires adult assistance.

Experiment: What's-a-Matter?

Question: Is air *matter* or *energy*?

Background information: Define *matter* and *energy* in your own words. You might know this from the lesson, or you may look it up.

Hypothesis: What is your educated guess?

Materials: Beaker or test tube, funnel, rubber stopper or clay, colored water, bucket.

Method:

1. Pour water through the funnel to show that it can flow freely.
2. Gently feed the stem of the funnel through the hole in the rubber stopper OR soften the clay and make a ring around the top of the flask or test-tube. Do not poke the stem through the clay or the stem will get clogged with clay.
3. Feed the stem of the funnel into the flask or test tube, sealing the opening of the flask or test tube tightly.
4. Quickly pour the colored water into the funnel.

Observation: Describe what you saw with your eyes, heard with your ears, etc.

Conclusion: Is air matter or energy? Why?

Set A – Matter vs. Energy

Matter	Energy
streetlight	light
horn	sound
firewood	heat
stardust	starlight
magnets	magnetism

Set B – States of Matter

Solid	Liquid	Gas
ice	water	steam
rock	lava	methane
iron (Fe)	mercury (Hg)	hydrogen (H)
cookie	juice	oxygen

Set C – Changes in States of Matter

State Change…	… is Called
solid to liquid	melting
liquid to gas	evaporating
solid to gas	sublimating
gas to liquid	condensing
liquid to solid	solidifying

Journey to the Center of Mass!

Center of Mass / Center of Gravity

Prerequisite Knowledge/Skills: None.

Isolated Difficulty: Center of Mass/Center of Gravity

New vocabulary: mass (vs. weight), equilibrium, vector

Direct Aim: Students will:

- participate in a simulation of mass and weight on different planets.
- understand that the center of mass of an object is an imaginary point which represents the point of equilibrium, as if all of the matter in the object could be concentrated in that single point.
- *represent* a force that is applied evenly to an entire object as the total force applied just to the Center of Mass (VERY basic vector diagrams).
- consider engineering and other problem-solving implications for Center of Mass.

Indirect Aim: Students will

- exercise children's budding capacity to use abstract reasoning to imagine things that cannot be experienced sensorially
- preparation for additional work with forces and vector diagrams.
- if children have studied basic statistics, children may recognize the Center of Mass as being analogous to the mean of a set of numerical data points.

Applicable Next Generation Science Standards:

3-PS2.A: Each force acts on one particular object and has both strength and direction. An object at rest typically has multiple forces acting on it, but they had to give zero net force on the object. Forces that do not some to zero can cause changes in the objects speed or direction of motion. (Qualitative and conceptual)…

5-PS2-1: Support an argument that the gravitational force exerted by earth on objects is directed down. Clarification: "down" is a local description of the direction that points towards the center of the spherical earth.

MS-PS2.A: … The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.

Preparation: Gather ahead:

4 identical boxes containing differing amounts of gravel to give an impression of comparatively how much a given mass weighs on Earth, Mars, Jupiter, and the moon. SEAL TIGHTLY! Label the boxes with the celestial body, not with the weight of the gravel. Here are the relative weights for each of the 4 boxes. They can be doubled or tripled or halved to fit appropriately into the 4 identical boxes. For the lesson, we will assume that the weights are as shown:

"Earth" – 200 grams
"Earth's Moon" – 33 grams
"Mars" – 76 grams
"Jupiter" – 506 grams

Optional: scale to weigh the boxes real-time with the children

A circle (measured with a compass and cut from card stock)

Very sharp pencil point or compass point

A straight-sided drinking glass

Cutout representing the drinking glass -- should be made from corrugated cardboard or foam core or thin wood or something else with sufficient thickness that it can stand on end on a table.
2 pencils, at least one with its eraser intact
Push pin attached to a Plum-bob on a string
Ruler
Photo of a car with a low center of gravity and of a truck with a high center of gravity
Photo(s) of construction cranes lifting a roof truss or cargo.
Pattern of a parrot with and without a long tail

Connecting to Prior Knowledge:

1. Ask the children to recall what they know about gravity. *They likely know that gravity is what makes things fall if you drop them and that Earth and the sun have gravity. If they have seen the lessons on Space Science at the beginning of this album, they know that gravity is what keeps the planets in our solar system orbiting around the sun, and what keeps the moon orbiting around Earth.*

2. Ask the children to share what they know about weight. *Accept any valid responses. It is greatly sufficient for this lesson if children know only that weight is a measure of how heavy something is. If they know more than that, please tailor the first bit of this lesson accordingly.*

Background information (mass vs. weight):

3. Weight as a measure of how heavy something is. It is the force that an object exerts because of gravity. Instead of asking how much something weighs, could we ask how much force the object exerts on the Earth – the answer would be the same.

4. Show the *Earth* box. Tell the children that inside the box, there is 200 grams of matter. (If you have an accurate scale, verify this with the children.) Let's take an imaginary trip – we blast off of Earth and into outer space. How much does our box weigh now, while we are in Outer Space? *Children will likely know that it, like all objects, would effectively be weightless.* Once we are outside the gravitational field of Earth, the box would be weightless.

5. But what happened to the matter inside the box? Did it disappear? *Of course not!* The matter is still inside the box, but since there is no gravitational field in space *(Teacher note: away from celestial bodies)*, the matter does not have any weight! Scientists have a term for the amount of matter; they call it the mass of the object. So we can say that the matter in the box has the same mass, but it has no weight because there is no gravity!

6. We are now landing on the moon. The moon has a gravitational field too, so our box will again have weight. Is the moon's gravitational field stronger or weaker than that of Earth? *The children may know that the moon's gravitational field is weaker than the Earth's because of stories from the third lunar landing, when astronaut Alan Shepard hit a golf ball on the moon.* In fact, the moon's gravity is about 1/6 that of Earth's because the moon is about 1/6 the size of Earth; the gravity of an object is proportional to its size. *Show the "Earth's Moon" box.* The same box of matter, the same mass, would weigh 33 grams on the moon. Pass the two boxes around.

7. If our matter weighs less on the moon, does that mean that there's less matter in the box? No. The amount of matter in the box does not increase or decrease. The mass is constant. It just

weighs more or less depending upon how much gravity there is. There is more gravity on Earth than on the moon, and no gravity in outer space.

In actuality, because we can't change the Earth's gravitational field, we are simulating the change in weight by having less matter in the box – we must use our imagination to say that the "Earth's Moon" box contains the same mass as the "Earth" box, but it weighs less because our moon's gravitational field is weaker.

8. Take the mass to Mars and then to Jupiter, exploring what that same mass would feel like on these different planets. Remark on how the size of the planet determines how strong or weak its gravitational field.

   Be sure to pass the sealed boxes around for the children to experience the different weights. At the end, reiterate that this demonstration simulates how much the *same mass* would feel in *different gravitational fields* on *different planets.*

9. Return to Earth and set the boxes aside. Ask a volunteer to explain the difference between mass and weight.

<u>New Learning:</u>

10. The name of this lesson is "Journey to the Center of Mass". We are going to explore the effect that gravity has on different masses.

11. Show the circle. Ask the children if it is possible to balance the circle on the point of a pencil. *Children will say that the balance point of the circle is its center.*
    Balance the circle on a pencil point right at this pinprick that was created by the compass when drawing the circle; the circle balances perfectly on the point. If we try to do this at other points on the circle, the circle slides off onto the floor.

    Move the circle to the point of a compass (smaller than the point of a pencil) and spin the circle to find that it spins evenly.

    This point is called the <u>Center of Mass</u>. This point is where, if we concentrated all of the mass of the circle – all of the matter of the circle, into that location, it would balance on the tip of the pencil.

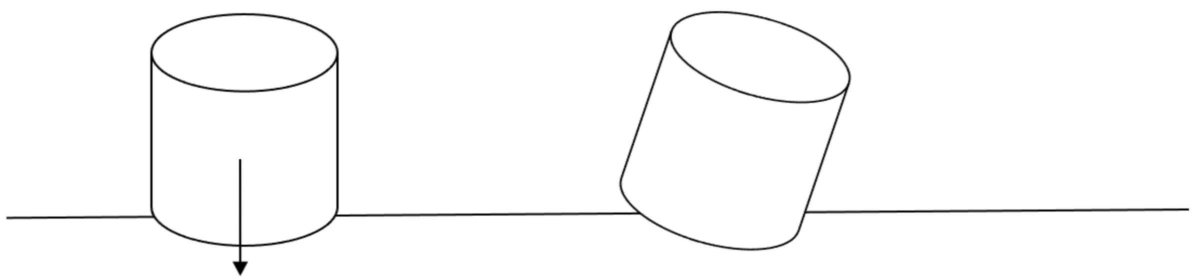
    Another way to think of the Center of Mass is that it is the point at which all forces balance each other out. For every bit of mass on the circle, there is a twin bit of mass on the opposite side of the circle, like a perfectly balanced teeter-totter. (The Center of Mass is at the center of the circle only because the card stock is the same thickness everywhere, so the distribution of the mass is consistent throughout. If the card stock were thicker on one end than the other, the Center of Mass would shift towards the thicker end.)

12. What about a 3-dimensional object – where is its balance point, the point where all the forces on all sides balance each other out? Where is its Center of Mass?

    Set the drinking glass up on the table or rug. Gently tip the glass slightly to one side and release it, allowing the glass to right itself. Repeat this demonstration several times, each time increasing the amount that the glass is tipped before releasing it. When the glass is eventually tipped over far enough to fall over, ask the children why the glass fell over. *The children will respond that the glass fell because you tipped it too far. This is exactly correct!*

13. Draw a picture of the drinking glass on the board and ask them to identify how gravity holds the glass to the table. *Accept all reasonable explanations*.

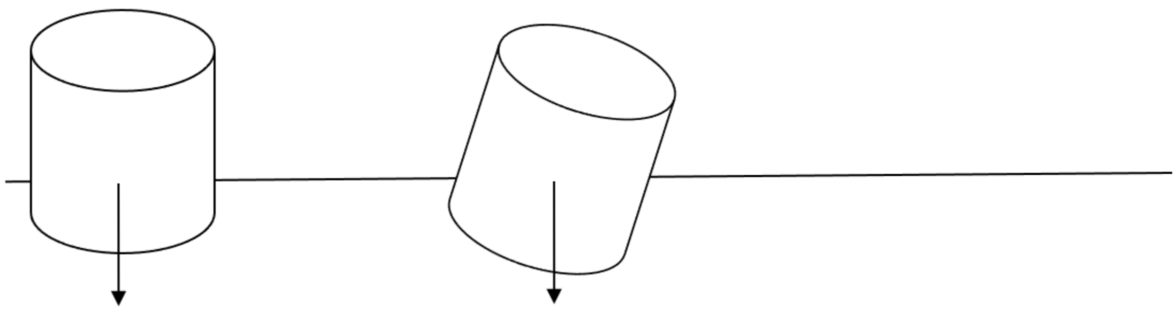
14. When gravity acts on an object, what part of the object does it act upon? Does one part of this mass get more effect of gravity than another?
    Gravity acts on each part of the mass, each molecule of the glass, equally. We could draw a tiny little arrow for each molecule of glass, but it would be impossible to draw them small enough AND we would be here forever. So instead, we use a single arrow to show the force due to gravity. (Draw it as shown in the leftmost drawing on the diagram below). Remember, gravity doesn't care what an object is shaped like -- gravity always results in a force pulling every molecule of the object towards the center of the Earth.
15. Draw a picture of the glass when it has been tipped over a bit but do not yet add the force vector. Why does gravity sometimes right the glass and sometimes tip it over? Let’s explore a simpler, 2-dimensional cut-out version of our drinking glass and then see how that might help us answer this question.



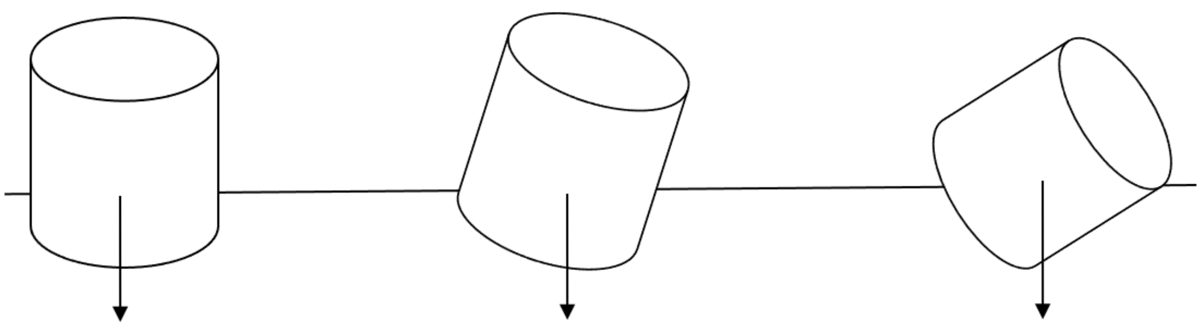
16. How would we find the center of this mass of this irregular shape? *Children might suggest trying to balance it on a point or to spin it on that point.*
17. After the children have had a chance to make their guesses, demonstrate the following method for finding the center of mass for the object that doesn’t involve trial-and-error:
    a. Tie the plum-bob onto the push pin.
    b. Push the push pin through any point on the perimeter of the glass shape.
    c. Push the push point of the push pin into the eraser of a pencil so that when you hold the pencil, both the outline of the glass and the plumb-bob dangle freely and independently.
    d. Mark the point where the string meets the far side of the cutout of the glass.
    e. The mark on the cutout and the prick from the push pin are two points that define a line. Lightly draw in this line with a pencil and ruler.
    f. Repeat this process from two more equally spaced points along the perimeter of the shape .
    g. The point where these three points meet is the center of mass of the shape.
    h. Balance the cutout of the glass on the tip of a pencil or compass at the point which was determined to be the Center of Mass. Spin the shape to show it spins evenly.
18. Why do we care about the center of mass? This is the most stable place on the object. If we add weight to the Center of Mass, the object remains stable. If we add weight outside the Center of Mass, the center of mass the object wants to tip or turn. (Optional – demonstrate by putting a clip on one edge of the cut out of the glass)
    The center of mass is the point where, if we concentrate all of the mass and all of the forces of the object, it perfectly simulates the object and all of its forces. In this case, what we drew before (step 7) is a vector. **A vector is an arrow that shows the magnitude and direction of a force acting on the Center of Mass of an object.**

19. Set aside the push pin, plumb-bob, and pencil. Hold the cutout of the glass up as if it were sitting on the table. Compare this to the sketch of the force due to gravity from step 7. The cutout of the glass acts as if all of the force due to gravity were concentrated at its Center of Mass, pulling it towards the center of the Earth.

20. Tip the cutout of the glass a little. Refer to the second sketch that shows the glass tipped. Where is the center of mass now? *The Center of Mass has not changed.* What direction is gravity pulling the object? *Towards the center of the Earth. Gravity doesn't care whether the glass is tipped or not.* Draw the vector on the sketch of the tipped class, showing that gravity is pulling down towards the center of the Earth through the base of the cutout:



21. Finally, tip the cutout of the glass at least 45º. The Center of Gravity has not changed, nor has gravity changed. The difference is that now, when gravity pulls down from the Center of Gravity of the cutout, the force pulls through the *side* of the glass. Before, it was pulling through the bottom of the glass.
    The glass tips over when the Center of Mass is no longer over the base of the glass.



22. Let's go back to the 3-dimensional drinking glass. We know where the center of mass is on the cutout of the glass. Where would it be for the 3-dimensional glass? *It will actually be inside the glass – in the middle of the air inside the glass.*

    Invite the children to imagine the Center of Mass of the drinking glass. *Tip the glass slightly and allow it to right itself.* Remind them that as long as the Center of Mass remains over the base of the glass, gravity will pull through the base of the glass and the glass will right itself. *Tip the glass to the point where it falls.* As soon as the Center of Mass is over the sides of the glass, the glass will fall on its side – gravity is pulling through the side of the glass.

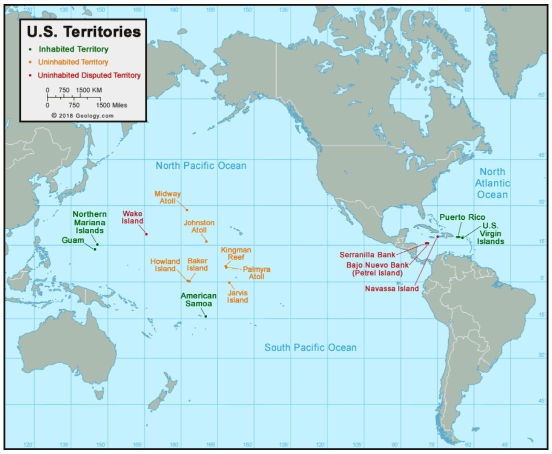
23. Applications of the concept of Center of Mass can be found in engineering designs, safe distribution of weight when loading a vehicle, and even in mapping!

a. Explain that the center of Mass / Center of Gravity of a vehicle is an important consideration of its design. Racecars are designed to have a low Center of Gravity so that when they take a turn at a high speed, they will not flip over.
Show a photo of an Indy Car or of a sports car with a low center of gravity. Panel trucks, like trucks that people rent to move themselves, are designed to carry a lot of cargo - they maximize the amount of storage space inside the vehicle without worrying as much about the forces on the vehicle in a high-speed turn.
Show a photo of a U-Haul or similar vehicle at a similar scale to the sports car. The center of gravity of the truck is much higher than that of the racecar, even when empty. As they load cargo into the panel truck, any weight that is put on the truck at a height lower than the Center of Gravity lowers the Center of Gravity. Any weight that is put on the truck at a height higher than the Center of Gravity raises the Center of Gravity. So if they load the heaviest items into the lower part of the truck and save the lightest boxes for the upper part of the truck, the truck will be more stable and less likely to tip in a turn or to rock side-to-side when going over bumps.

https://newatlas.com/2018-subaru-brz-ts-review/56357/ *https://www.uhaul.com/Truck-Rentals/15ft-Moving-Truck/*

The same idea can be used when loading up the family vehicle. If some items need to go on the top of the car, they should be the lightest-weight items. Put the heavier items into the car itself, preferably on the floor of the vehicle.

b. The Center of Gravity of an object is also important to know when lifting items from a construction crane. *Show a photo of a construction crane lifting a roof truss or cargo boxes.* Discuss what would happen if the crane were to lift from the point which is not at the center of gravity- for example, if the cargo container was filled with heavier items on one side than another. *Phot credit: https://www.ilec.coop/news-and-events/news/must-have-details-for-a-new-or-remodeled-home*



c. Center of Gravity in engineering designs is found mathematically. But it hasn't always been so. In 1918, the Coast and Geodetic Survey, a US federal agency that is responsible for defining and managing the national coordinate system, wanted to find the geographic center of the contiguous US (the lower 48 states). They did so by balancing on a point a cardboard cutout shaped like the U.S. they found it to be near the town of Lebanon, Kansas. Later modeling and calculations have shown that this method was accurate to within 20 miles.

Adding the states of Alaska and Hawaii in 1959 was *https://geology.com/state-map/us-territories.shtml* interesting! This shifted the geographic center of the US to Belle Fourche, South Dakota.

What effect might there be to including the 16 US territories? These range from Puerto Rico, with over 140 smaller islands and over 3 million residents, to uninhabited territories (and disputed territories) such as Bajo Nuevo Bank, Navassa Island, Serranilla Bank, and Wake Island. What about the island nation of Indonesia, or perhaps Sweden and Norway (each have over 200,000 islands)? What about the geographic center of the Ancient Roman Empire? (For fun, search the internet for "raised relief map of the Roman Empire".)

Follow-up options (choose one or mix and match):

Knowledge:

d. Invite children to create a variety of 2-dimensional figures and then predict and find their centers of gravity.
e. Invite children to explain under what circumstances a tipped object will right itself with appropriate sketches. Note: children are quite prone at this age to tipping their chairs backwards. This presents a risk of serious and permanent damage if one lands with full-body weight on one's neck. If this discussion can be had without encouraging experimenting, it can provide relevance…

Comprehension: Invite children to predict the Center of Mass of objects based on their appearance. *See attached Lab for one example.*

Application: children might be inspired to conduct personal interest work on any of the following topics:

f. Comparing center of gravity on a variety of commercial vehicles
g. The effect of increasing the wheelbase on rates of roll-over crashes
h. Experimenting with a teeter-totter (playground equipment or a model constructed in the classroom) to see the effect of adding weights at various distances from the fulcrum on each side. *They may deduce the relationship that the weight x the lever arm (distance from the fulcrum) is a measure of the force. Therefore, a weight of 2 g. at a distance of 4 cm. will balance a weight of 8 g. at a distance of 1 cm. or 1 g. at a distance of 8 cm.*
i. If there is a class bird feeder, children might be interested in comparing how birds with long tails (magpies, flickers, etc.) compensate for their long tails when landing or perching.

Extension: Cross-curricular extension – writing: write a story or a skit about traveling to different planets, experiencing different gravitational fields and explain how weight changes but mass does not.

Lay It On Me!

Layers of the Earth

Prerequisite Knowledge/Skills:

- Children *may* have prior knowledge of the layers of Earth by composition (inner core, outer core, mantle, and crust). They *may* also understand that density is somehow different from weight. Neither is required for children to be successful with this lesson.
- Children should know the three states of matter and how temperature determines a material's state.

Isolated Difficulty: Two ways of defining Earth's layers: by composition and by physical/mechanical properties.

New (and old) vocabulary: density, crust, continental crust, oceanic crust, mantle, outer core, inner core, lithosphere, asthenosphere, mesosphere.

Direct Aim: Children will:

- revisit the layers of Earth
  - use the concept of density to explain layers by chemical composition
  - use states of matter to define layers by physical/mechanical properties
- expand their understanding of states of matter to know that this is determined by temperature *and pressure*

Indirect Aim: Children will:

- understand that the Earth is dynamic, constantly changing.
- lay the foundation for crustal movement (plate tectonics and oceanic spreading)
- lay the foundation for structures that occur due to crustal movement (folding, faulting, earthquakes, and volcanoes)
- consider the difference between a theory and a fact

Preparation: Gather ahead:

Displays per lesson (b/w versions follow)
OPTIONAL: clear plastic box with several dense metal chunks and a few packing peanuts
A jar and at least 3 immiscible liquids of differing densities (water, oil, rubbing alcohol)
OPTIONAL: – 2 fresh bars Ivory soap
A clear, shallow basin
A piece of paper smaller than the diameter of the basin
Paper clips, gravel, or other small objects to provide incremental weight
OPTIONAL FOLLOW-UP: historical theories cards (provided)

<u>Connecting to Prior Knowledge:</u>

24. Invite children to discuss what they know about the formation of Earth and Earth's layers. *Accept all relevant and correct contributions. Know that children's understanding of the layers of the Earth may be as basic as analogy to the white and yolk of an egg or the pit and fruit of an avocado, or it may include knowledge of the terms crust, mantle, outer core, and inner core. Fill in whatever gaps there are in their knowledge:*
    a. About 14 billion years ago, the Big Bang, is theorized to have sent out unimaginable amounts of gas, dust, and atomic particles.

b. Scientists tell us that as these bits of cosmic dust ran into one another, they were so hot that they stuck together – something that we see today when a volcano erupts and sends out superheated ash.
c. Scientists say that Earth formed about 4.5 billion years ago when gravity pulled swirling gas and dust in to become the third planet from the Sun.
d. Scientists believe that, like its fellow terrestrial planets, Earth has layers.

New Learning:

25. All of these things are *theories*. Scientists develop theories by creating a model. These models are sometimes physical models – something that they build and test - and sometimes they are theoretical models – models of ideas that exist on paper or in computers or in the minds of scientists that they test mathematically.
    a. These models use laws of physical science that apply on Earth or under test conditions. For example, we know how forces act on objects on Earth and in weightless conditions and can use that information to make theories about how things happen on Earth and in space.
    b. These models also use observations made in modern day. For example, we can observe a modern-day supernova and use what we see there to explain how the Universe could have been created by The Big Bang. There have been recent observations of far-away galaxies that challenge some parts of The Big Bang Theory. When scientists make new observations that don't quite fit the existing model, they look at the theory/model to see whether it can be modified to explain the new observations or not. If not, they may develop a new theory/model. https://www.space.com/25126-big-bang-theory.html
    c. These models also use complex mathematics and computer programming. For example, astronomers who study the movement of dwarf planets and other icy objects have noticed that there are irregularities in their orbits. These irregularities could be explained by the existence of another planet that could be as big as Neptune, orbiting the sun at a distance 20 times farther than Neptune. If *Planet X* does exist, it might take 10,000 – 20,000 years to make a single trip around the sun, which could help explain why it has never been seen. https://solarsystem.nasa.gov/planets/hypothetical-planet-x/in-depth/

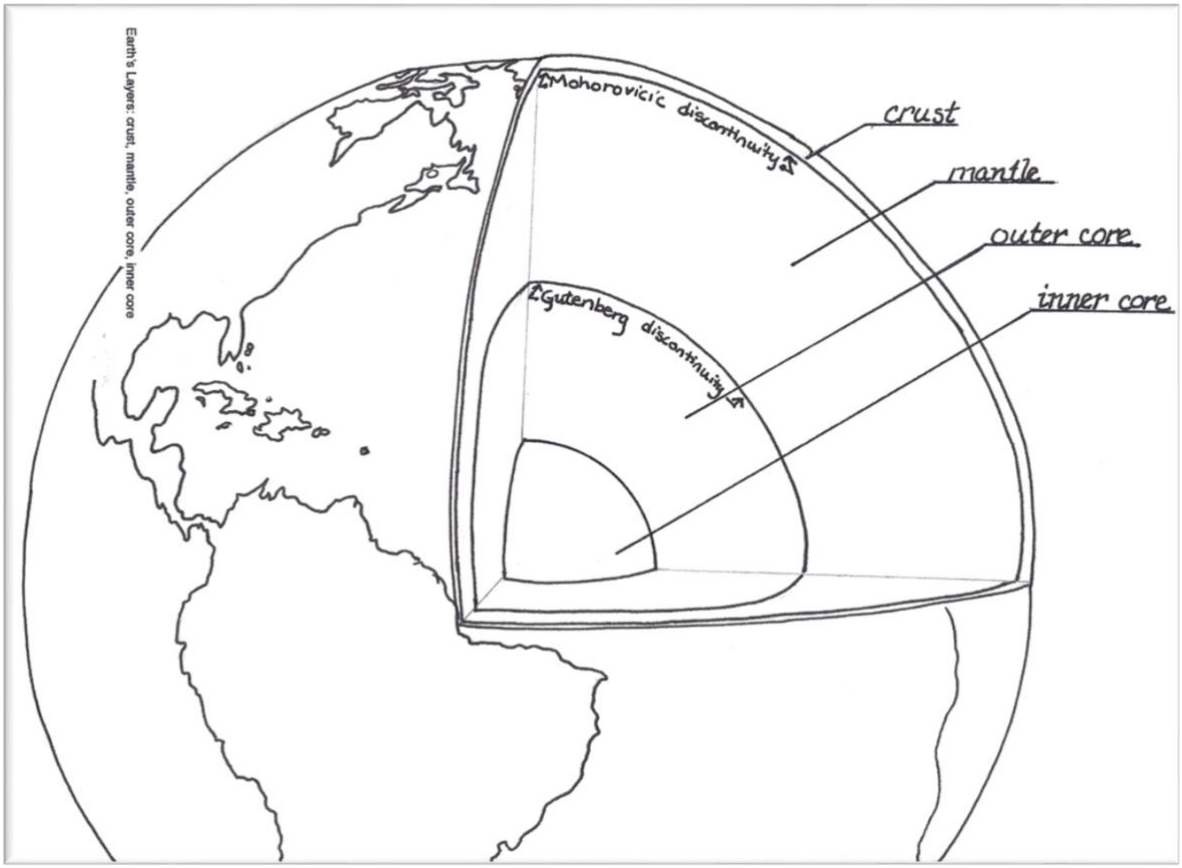
26. Ask the children why scientists might be interested in the composition of Earth's interior. *Entertain all reasonable thoughts on the subject. If needed, add that the better scientists understand what is happening inside the Earth, the better able they are to explain things that happen on the Earth's surface.*

27. Scientists have two ways of describing Earth's layers. Each is useful in different ways. Both are highly idealized models. There are no bold, clear differences between layers. One layer grades gradually into another and the thicknesses of each layer are very approximate.

Layers Defined by Chemical Composition / Density

28. One system defines the layers based on what the rock is made out of – its chemical composition. In this model, there are 3-4 layers
    a. Crust – We live on the crust, which is made up of solid rocks and minerals. It is the thinnest layer, but it is not uniformly thick.
    There are two kinds of crust: continental crust – the crust that makes up the continents – and oceanic crust – the crust/rock under the ocean. Oceanic crust (5-10 km thick) is thinner than continental crust (10-70 km thick). *NOTE*: *The oceanic crust does not include the oceans – just the rock under the oceans*.

b. Mantle – this is the biggest of Earth's layers by volume. It is composed of different types of rock than the crust - - it is denser. It extends from the crust to a depth of about 2900 km.
c. Core – this is the densest part of the earth. It is thought to be made up of heavy metals – mostly iron and nickel. 6400 km (about 4000 miles).



29. These layers formed because when the Earth was still molten, before it started to cool and solidify, the densest materials sank, and the least dense materials floated.

Density is sometimes hard to understand because it is similar to weight, but not the same. Children may have studied the concept of density previously in Space Science (What Goes Up Must Come Down.) If so, refer to those experiences.

If children have previously studied mechanics, refer to the idea that gravity pulls objects towards the center of the planet. The amount of pull is proportionate to the amount of matter: denser things, things with more tightly packed molecules, sink because gravity has more molecules to pull on. If they have not previously studied mechanics, it may be worth pulling out a globe and exploring what "down" means on opposite sides of the planet.

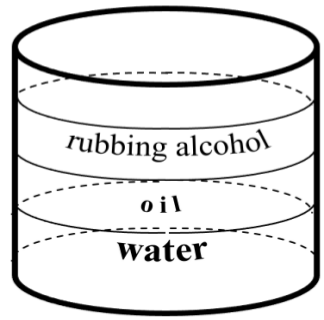
Whether they have previous experience with density or not, it is worth spending a few minutes on the concept.

When we speak of the density of a substance, we refer to how tightly packed the atoms are in that substance. When atoms are more tightly packed, the substance is denser. If we compare

two identically sized objects with different densities, the denser object will weigh more because there are more atoms packed into the object.
If we speak of the population density, it can mean the number of people per square mile.
OPTIONAL: Have the children squish into one corner of the room so that they are densely packed into the space. Then have them spread out so that they are as far as possible from other classmates, so they are less densely distributed in the room.

Children may have seen a demonstration in E-I showing that denser materials tend to sink to the bottom while less dense materials float. This is classically done with a clear plastic box of sand on the surface of which are placed some dense pieces of metal and a few packing-peanuts. As one shakes the box of sand back and forth, the metal chunks sink to the bottom while the packing-peanuts stay at the surface. If children have not seen this demonstration in lower elementary, it is wholly appropriate to show it now.

We can compare the density of three liquids, in this case oil, water, and rubbing alcohol. Pour each of these liquids carefully and slowly into a jar. (It often helps to pour down the inside edge of the glass.) The liquids form layers. The densest layer, water, is on the bottom, with the least dense layer, rubbing alcohol, on top. Materials that are less dense float, while materials that are denser sink. This is true whether the material is a solid, a liquid or a gas.



OPTIONAL: Demonstrate density of solids using two FRESH bars of Ivory® soap. Place one bar on a microwave-safe glass or porcelain plate (not paper or plastic). Put the plate in the center of the microwave and turn it on for 60-90 seconds. As the soap heats up, air trapped in the soap expands, giving the bar of soap the appearance of an expanding thunderhead on a hot summer day. When the soap is removed from the microwave (initially quite hot!) it weighs the same amount as it did when it was put into the microwave (less a little water vapor), but it is far less dense. *NOTE: a lot of perfume is released when the soap is heated. The scent remains in the classroom and in the microwave for some time. If there are children in the class that are sensitive to scent, it might be best to microwave the soap ahead of time and reveal the final product in the lesson. To supplement this, show the video where science superstar Steve Spangler does this experiment. https://www.youtube.com/watch?v=z1hzatoE1tg.*

30. Among all the materials that make up Earth, the densest are in the core. The mantle is less dense than the core, and the crust is the least dense, with the oceanic crust denser than the continental crust. If we draw an analogy to the liquids that we previously layered, the core is like the bottom layer, the mantle is the middle layer, and the crust is the top layer, with the oceanic crust at the bottom of that layer and the continental crust at the top of that layer.

Layers Defined by Physical/Mechanical Properties (State of Matter)

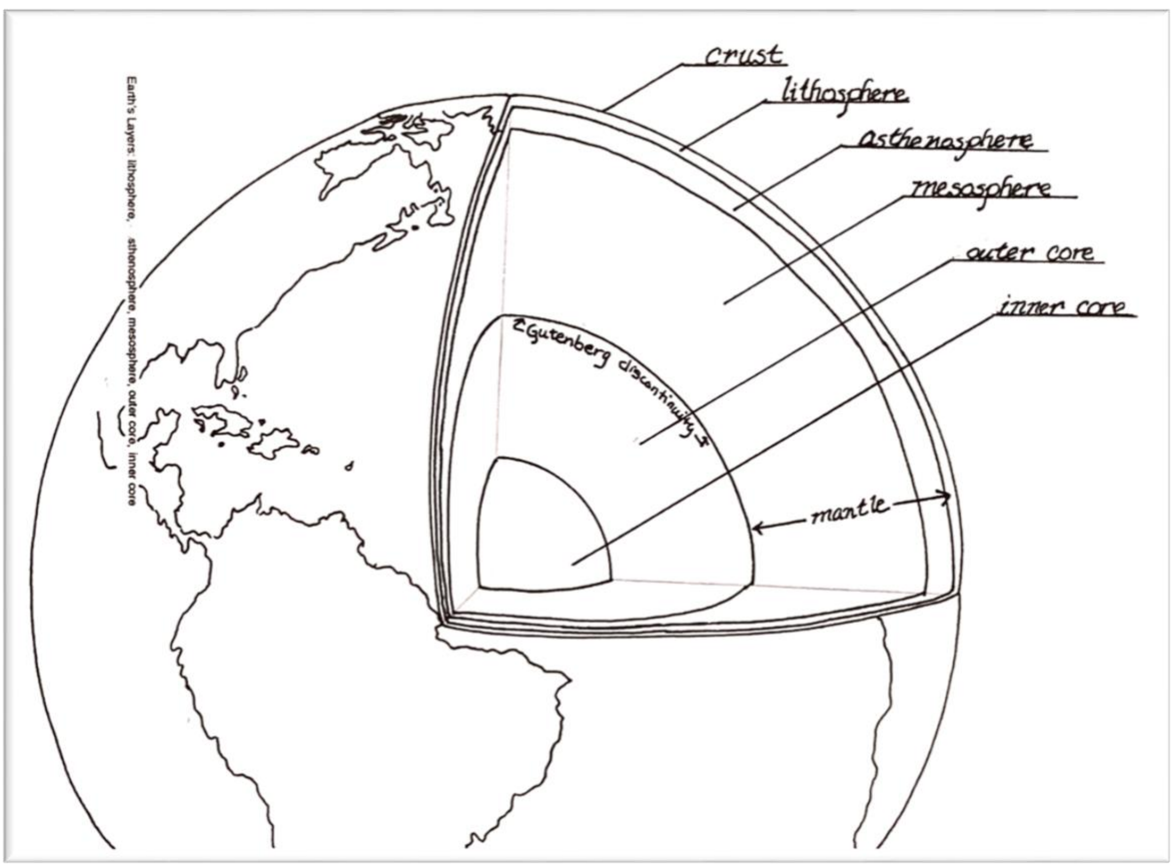
31. Another way to describe Earth's layers is by the physical characteristics or mechanics of each layer. This distinguishes between layers mostly by which state of matter makes up that layer. The layers are described as follows:
    a. Lithosphere (Layered Sphere) – This is the top layer. It is rigid – a solid layer of rock. It includes all of the crust plus the uppermost, coolest, solid portion of the mantle. This layer is 10-200 km (6 – 125 miles) thick, depending upon where you are on Earth. (Usually closer to 200 km than 10 km.)

b. Asthenosphere (Weak Sphere) -- Tremendous heat and pressure make this layer behave like a semi-solid. It is not exactly a liquid and not rigid like a solid. This syrupy, gummy, putty-like layer has currents within it – the molecules can slide past one another. The Asthenosphere extends to a depth of about 660 km (410 miles).

c. Mesosphere (Middle Sphere) – Chemically, the composition of the mesosphere is the same as the asthenosphere. But the pressure is so great that, even though it is quite hot, the atoms and molecules are so tightly packed that the rock cannot be in a molten state – it is mostly solid. This layer is the innermost part of the mantle and extends to a depth of about 2900 km (1800 miles). *There is also a layer of the atmosphere that is also called the mesosphere – the middle sphere.)*

d. Outer Core. – The chemical make-up of the core is different – it has a much higher proportion of metals, mostly iron mixed with smaller amounts of other elements such as nickel. So even though there is tremendous pressure – more than was in the mesosphere, the temperatures are also higher, so the outer core is liquid. The liquid outer core extends to a depth of about 5100 km (about 3200 miles).

e. Inner Core - Current thinking is that the outer core is made up of the same materials that are in the outer core, but the pressure has risen to the point where the inner core is a solid. This extends to the center of the earth, at a depth of 6400 km (about 4000 miles)- the radius of the Earth.

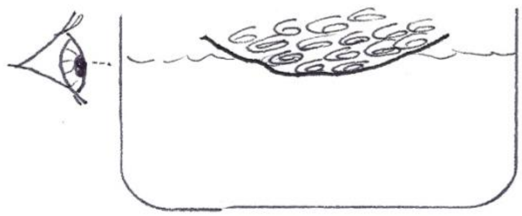


32. Generally speaking, these layers don't have distinct boundaries – they kind of transition from one into the next. However, the boundary between the lithosphere and the asthenosphere is pretty dramatic, as is the boundary between the mantle or mesosphere and the outer core. Scientists call

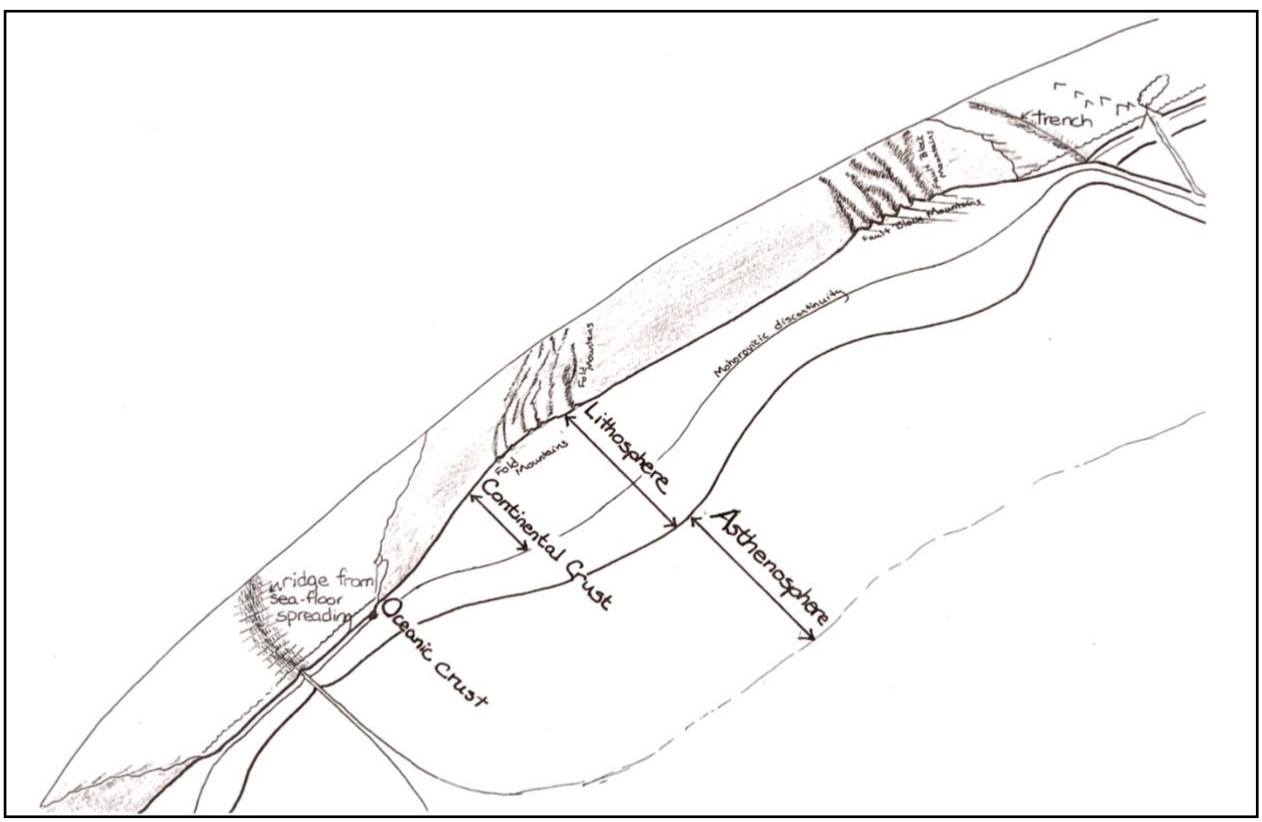
this kind of sudden change a discontinuity. These discontinuities are called the Mohorovicic Discontinuity (or Moho, for short) and the Gutenberg Discontinuity.

33. Of all the layers, the crust/lithosphere has the greatest variability in thickness. The crust is thickest under the mountains and thinnest in the deepest parts of the oceans. But it might not be for the reason that you think!

Put a small pile of paperclips on the table. If we based our theories purely on what we could see from the Earth's surface, we might think that the crust is thicker because there is more material builds up above sea level, like these paper clips on the table. But that is only half of the story. Remember, the solid, rigid lithosphere floats on top of a semi-solid, the asthenosphere. So the lithosphere/asthenosphere boundary behaves a little like an iceberg: the semi-solid asthenosphere moves out of the way under the weight of the solid lithosphere, just like some of the ice in an iceberg displaces the water – some is below the surface of the water.



Put a few inches of water into a clear basin. Float a piece of paper on the surface of the water. Place paper clips in the center of the paper, one at a time. After a few (approaching a dozen) paper clips have been set onto the paper, observe the paper through the side of the basin and from above. Notice that the paper is bowed below the surface of the water where the added weight of the paperclips is pushing down on the paper. As the height of the paper clip mountain grows, the center of the paper sinks. Yet the water does not flood the paper because the edges of the paper are still floating on the surface of the water. This is why the lithosphere of the Earth bows down under mountains.



How did scientists come to these hypotheses about the Earth's interior? Certainly not by directly observing the lithosphere / asthenosphere boundary! Remember that the lithosphere is thought to be, on average, 100 km (60 miles) thick. At its thinnest, it is 10 km (6 miles) thick.

- The Grand Canyon is about a mile deep.
- The deepest mine is only 3.8 km (2-1/3 mi) deep, in Carletonville, South Africa.
- The deepest well started from the continental crust is only 15 km (9 mi) deep, in Zapolyarnyy, Russia.
- The Marianas Trench in the Pacific Ocean is only 7 miles deep.

These hypotheses are built on <u>indirect observation</u>. These descriptions of the Earth's layers are based upon a <u>theory</u> that fits all of the observations made by scientists.

<u>Follow-up options (choose one or mix and match):</u>

Knowledge: Invite children to create their own diagrams of the 2 methods of naming Earth's layers. These drawings can be done free-hand or children can be provided black-line masters of the three diagrams that follow after whiting out all of the relevant terms.

- For the nomenclature related to the chemical composition (density) of the layers, they might color-code the layers using deepest shades of a hue for the densest material and the lightest shade for the least dense. (They should distinguish between oceanic and continental crust.).
- For the nomenclature related to the physical/mechanical attributes of the layer, they might color code the layers according to whether they are a solid, a semi-solid, or a liquid.
- Children can repeat any of the demonstrations from the lesson
- Children might enjoy learning a song or rap about the Earth's layers. Most (maybe all) on YouTube use the nomenclature related to the chemical composition/density of the layers. After learning one song, they may feel compelled to create a new song using the nomenclature based related to the physical/mechanics properties of the layers.

Comprehension: Invite children to create "Who am I" cards or to create cards for a Concentration game that matches the name of the layer and its description. Once they have created the cards for the game, they will likely choose to play it again and again.

Application:

- Invite children to experiment with a semi-solid by combining corn starch and water. (Note: this will be a demonstration in an upcoming lesson showing why rocks subjected to forces sometimes fault and sometimes fold; when the proportions are correct, moving a utensil slowly through the mixture will cause the mixture to flow, while abrupt movement will cause the mixture to appear to break.)
- Invite children to create a physical model of Earth's layers based on either set of nomenclature. For the nomenclature related to the chemical composition/density of the layers, the relative density of the materials used should progress from the densest core to the least dense crust. For the nomenclature based related to the physical/mechanics properties of the layers, they will need to devise a way for a solid to be embedded in a liquid which is surrounded by a solid and then a semi-solid and then another solid. It can be done!

<u>Extensions</u>:

- Math extension: invite children to use the average thicknesses of each layer to create a scale drawing of a cross-section of the earth along one radius. This really drives home how thin the crust really is!

- Historians in the group may enjoy laying out a timeline of theories that have been held about Earth's interior (cards follow). These cards, covering the developments in theories about the Earth's interior, illustrate courage shown by these philosophers and scientists, as new scientific theories were often met with hostility and even violence. This may inspire further research into the Plutonists and the Neptunists, each of whom understood part of what we now believe to be true, or into other (possibly more contemporary) groups who vehemently disagree on scientific theories.

Note to teachers: These models are constantly being studied and refined. The newest models don't refute the old ones – they just add more detail. For example, more recent models divide the mantle into the upper mantle (which includes the lithosphere and asthenosphere), the transition zone, lower mantle, and D" (D double-prime) layer. For more information, see this very well written article: https://education.nationalgeographic.org/resource/mantle. In the vast majority of cases, this level of detail will be beyond the reach of the children, but it is an interesting read that provides insight into the level of detail that scientists are able to discern!

Aristotle **284-322 BC** This Greek philosopher said that the Earth was a solid ball. This theory was widely believed without challenge for over 2000 years!
General Populace **17th and 18th centuries** Many theories developed about the Earth's interior. Most theories in some way incorporated the idea that the oceans were, at least in part, a result of Noah's flood. Some thought that the Earth was a thin shell housing a watery interior.
Neptunists **Late 18th Century** These theorists believed that the Earth once had a solid core, covered by water, surrounded by chemicals that slowly settled out to make the rocks that are now at the surface. This differed greatly (and violently) from the Plutonists' view from this time

Plutonists
Late 18th Century

These theorists believed that the Earth had a molten interior that erupted onto the surface through volcanoes. Since there were few volcanic eruptions at the time, even Plutonists did not view volcanoes as particularly significant.

Geologists
1870's

The volatile arguments between the Plutonists & the Neptunists had mostly stopped. Geologists agreed that the Earth probably had a solid central core surrounded by a liquid mantle and a solid crust. However, they had no proof of this theory.

Seismologists
1900 - today

These scientists study patterns of energy waves (like those from earthquakes) to learn more about the subsurface. By 1900, seismologists found that the core behaves like a liquid and the mantle behaves like a solid.

Inge Lehmann
1888-1993

This Danish geophysicist proposed that the inner core is solid -- only the outer core is liquid. This was confirmed in 1970 with the advent of more sensitive and accurate seismic instruments.