TEACHER LESSON PLAN
Pack It In - Grain Packing Competition

Standards:

Elementary TEKS (K- 5th)	Middle School TEKS (6th – 8th)	ESS TEKS	Enviro. Sys. TEKS	AP Enviro. Sci	NGSS
K – 1.A, 1.C, 1.D, 1.E, 1.F, 2.B, 2.C, 3.A, 3.B, 3.C, 5.A, 5.B, 5.C, 6, 10.A, 11 1st – 1.A, 1.C, 1.D, 1.E, 1.F, 2.B, 2.C, 3A., 3.B, 3.C, 5.A, 5.B, 5.C, 6.A, 10.A 2nd – 1.A, 1.C, 1.D, 1.E, 1.F, 2.B, 2.C, 3.A, 3.B, 3.C, 5.A, 5.B, 5.C, 10.A 3rd – 1.A, 1.C, 1.D, 1.E, 1.F, 2.B, 2.C, 3.A, 3.B, 3.C, 5.A, 5.B, 10.B 4th – 1.A, 1.C, 1.D, 1.E, 1.F, 2.B, 2.C, 3.A, 3.B, 3.C, 5.A, 5.B, 5.C, 11.C 5th – 1.A, 1.C, 1.D, 1.E, 1.F, 2.B, 2.C, 3.A, 3.B, 3.C, 5.A, 5.B, 5.C, 10.B,	6th – 1.A, 1.C, 1.D, 1.E, 2.A, 2.C, 3.A, 3.B, 3.C, 10.A, 10.C 7th – 1.A, 1.C, 1.D, 1.E, 2.A, 2.C, 3.A, 3.B, 3.C, 10.A	1.A 1.E 1.F 2.B 2.C 3.A 3.B 9.B 9.C 13.A 13.B	1.A 1.B 1.D 1.E 1.F 1.G 2.B 2.C 3.B 3.C 7.A 7.B 12.A	4.2 4.3 4.6 6.3 6.4 6.5	K-2-ETS1-2 2-ESS1-1 2-PS1-1 4-ESS1-1 5-ESS2-1 MS-ESS1-4 MS-ESS2-1 MS-ESS2-2 MS-ESS3-1 HS-ESS2-1 HS-ESS2-2 HS-ESS2-5

Level: K-12

Objective:

This hands-on activity is designed for students to investigate how the size of sediment grains influences the porosity of soils and rocks. By completing this activity, students can visualize how sediment sizes affect the size of the pore space and investigate how this impacts the volume of fluids that can be stored in the pore space.

This activity can also support content related to aquifer recharge and how precipitation run-off is influenced by the porosity of soil. In addition, the porosity and permeability of rock formations influences where oil and natural gas are stored in the subsurface.

Background Information:

Porosity and permeability of soil types is a common topic in science courses of all levels. However, porosity and permeability of rocks is also applicable when students learn how fluids move through different soils.

By creating a grain mixture using various sizes of marbles or beads, students will learn how the ratio of bead sizes influences porosity. This can be connected to water storage in the subsurface (aquifers) and related to why oil and gas resources are found in certain areas in the subsurface. Discuss with students that oil and natural gas are stored in this pore space.

Time Requirements: 30 – 40 minutes

Teacher Preparation:

Materials:

The full list of materials is available in Table 1 and scales with the number of participants. Even if there are many participants, we suggest that they are divided in groups of 3-5 at a time for better management of the event. At the very minimum, we suggest use of three different marble or bead sizes such that each subsequent size is at least twice the previous one (e.g., 6mm,12mm, 25mm). It is easy to purchase an assortment of sizes in one package online. The student handout and the teacher will guide students when measuring the porosity of their marble/bead packings.

Fig.1. Marble sizes; the image is taken from https://www.rainbowturtle.com/category_s/1847.htm

Material	Quantity	Notes for Instructor
Marbles or Beads	3 different sizes (e.g., 5mm, 12mm, 25mm) with 10/participant for the smallest size, 5/participant for the medium size, and 1/participant for the largest size	At the very minimum, we suggest the use of three different marble sizes such that each subsequent size is at least twice the previous one.
Clear plastic cups	1 200-ml (or similar) cup/participant	
Graduated cylinder or measuring cup	1 200-ml volume-scaled container/participant	200 ml is the minimum size.
Water	200ml/participant	Scale up if your cups/containers are larger than 200ml.
Paper, pen and a marker	One for each per person (demonstrator) measuring the pore volume for all participants	

Table 1. Materials for grain packing activity

Procedure:

Have the materials prepared based on the assumed number of students.

1. Mark a line at the same height near the top of each of 4 clear plastic cups.
2. Divide students into groups of 3-4 individuals and assign each group a number. Group members are assigned roles: (1) constructor, (2) equipment manager and (3) recorder.
3. Explain the concept of porosity (for instance, using Fig. 1 as the motivation and Fig. 2 as a schematic to clarify the concept). Point out that porosity does not depend on the marble sizes in themselves, but more on how they pack together. Direct the recorder in each group to make notes about the ratio of marble/bead sizes chosen to pack their container. This information will be used to compare volume differences and determine how the ratio of sizes played a role.

4. Present the participants with the marbles (separated by size in different containers) and ask them to create their own packings while trying to reduce the porosity as much as possible. The marbles need to be packed so they go higher than the marked line. The winner will be the participant with the packing of the smallest porosity (actual water volume filling the pores in between the marbles, as measured by the demonstrator/instructor).

5. The group member designated as the constructor is responsible for packing, the group member designated as the equipment manager is to fill the graduated cylinder with water to a given level (original volume), e.g., up to the 200ml line (see Fig. 2a). The group member designated as the recorder is responsible for documenting the data for the activity.

6. When the first group is ready, pour the water from the graduated cylinder and fill it up to the marked line on the cup, and not higher. Students observe the remaining level (final volume) of water in the graduated cylinder (say 150ml) (Fig. 2b). How much water is in the pore space? The water volume in the pore space is the difference between the original volume and the final volume of water in the graduated cylinder (in our example, 200ml-150ml=50ml). The recorders for each group are to write the name of the group and the volume data collected/calculated in the table.

7. To complete the data table, the recorder in each group is responsible for obtaining the group number and volume for each of the other groups.

<u>For clean-up</u>: Separate the materials and have a place to empty or drain water. Use a piece of mesh to keep smaller beads/marbles from entering the drain of the sink. A suggestion is shown in Fig. 2c.

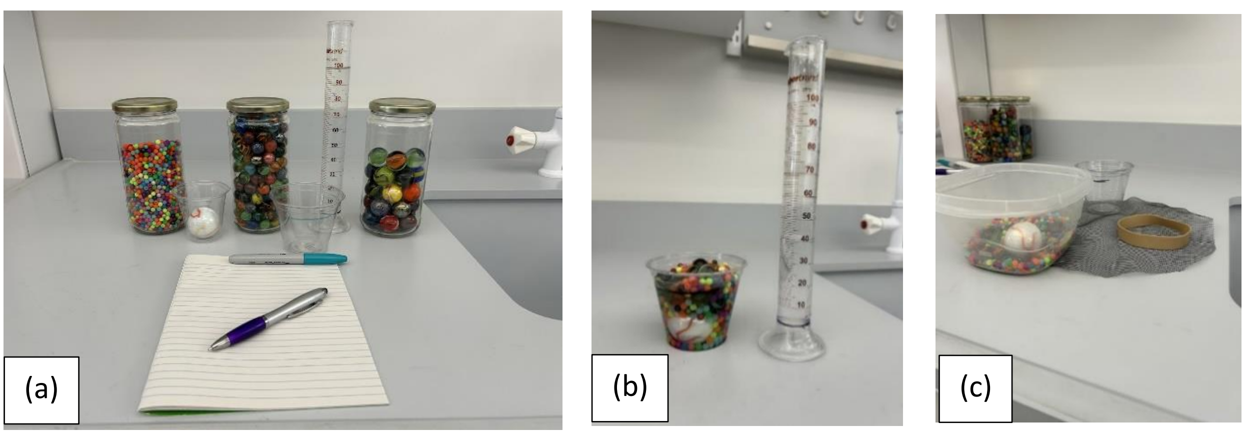

Fig.2. (a) Materials used in the activity. (b) Example cup filled with marbles. (c) Clean-up suggestion.
Photo Credit: Sabrina Ewald and Maša Prodanović

<u>Acknowledgment</u>: This grain packing competition exercise is adapted from the award-winning simple concept activity submitted by Dr. Ayaz Mehmani for the Hildebrand Department of Petroleum and Geosystems Engineering, The University of Texas at Austin *Simple Concepts Competition* (organized by Dr. Prodanović) when he was a student in 2012.

Extension A:

A further extension can ask students to compare the porosity for ordered (cubic) packing between rocks of different uniform grain sizes. In this example, a 2D calculation is used as an analogy to a more complicated 3D model. Thus, calculations will determine the area of squares and disks (2D), rather than the volume of spheres and cubes (3D).

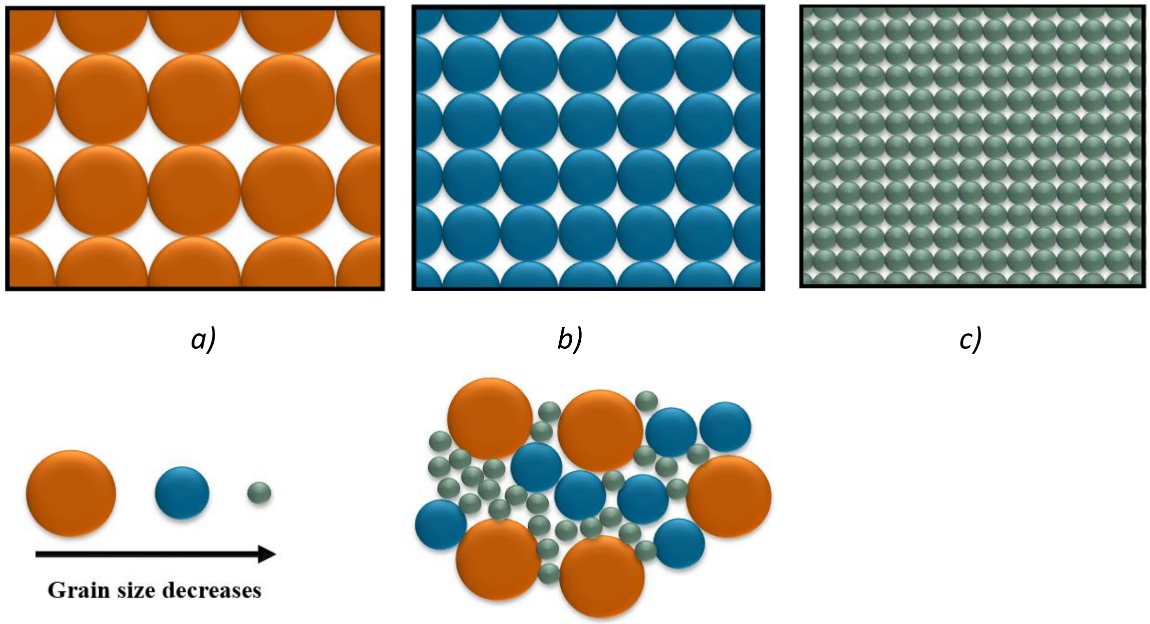

Fig.3. Schematics of ordered packing of grains in two dimensions (2D) of three decreasing grain sizes (a, b, c) and disordered (haphazard) packing (d) of these same grains where smaller grains are filling between the larger ones. Schematics Credit: Sabrina Ewald

In Fig. 3a-c, we have three marble packings of uniform size represented in 2D by disks. Do you think the porosity of the different packings differs based on disk size? Can you prove it mathematically using these diagrams? Calculate the porosity of the packing shown in Fig. 3a. We will use mm for units and select a ‘unit cell’ (shown below) from Fig. 3a.

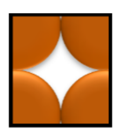

Fig 4. Unit cell corresponding to Fig. 3a. Schematics Credit: Sabrina Ewald

Next, determine the porosity of a cell by subtracting the area of the void space (white) from the area of the entire cell. What percentage is the void space?

You can assume that the radius of disks is r=2mm and recall that the area of a disk is πr^2.

The area of the block in Fig. 4 is 4mm x 4mm = $16mm^2$. The total area of the four disk quarters below is $\pi r^2 = \pi(2mm)^2 = 3.14(4mm)^2 = 12.56mm^2$. Thus, the area of the void space is $16mm^2 – 12.56\ mm^2 = 3.44mm^2$. And the porosity = $3.44mm^2 / 16mm^2 = 0.215$ or 21.5%.

Is it enough to consider only one "unit cell" shown in Fig. 3a? Why or why not? How many of these unit cells can you fit into Fig. 3a?

What if we select a smaller size grain (e.g., Fig. 3b). Continue to use the example cell unit shown in Fig. 4. But this time, you can assume that the radius of disks is r=1mm and recall that the area of a disk is πr^2.

The area of the smaller block is now 2mm x 2mm = $4mm^2$. The total area of the four disk quarters is $\pi r^2 = \pi(1mm)^2 = 3.14(1mm)^2 = 3.14mm^2$. Thus, the area of the void space is $4mm^2 - 3.14mm^2 = 0.86mm^2$. And the porosity = $0.86mm^2 / 4mm^2$ = 0.215 or 21.5%.

As long as the grains display ordered cubic packing and are of uniform grain size, a container full of beads of all large size beads will have the same porosity as a container full of beads of a smaller size bead.

Extension B:

Porosity ϕ (Greek letter 'phi') and **density ρ** (Greek letter 'rho') are the most commonly used measurements of soil and rocks. Porosity is a dimensionless number that simply refers to the fraction (or percentage) of the pore space within the entire soil or rock sample. If we use fractions, then porosity is always between 0 (purely solid) and 1 (purely void), or between 0 and 100%. Therefore, porosity does not depend on the sizes of grains comprising rock or soil. Density ρ is the mass per volume of the sample and the units are kg/m^3 or g/cm^3. It is important to recognize, however, that for porous samples such as soil or rocks, the voids could be filled with any fluid (and different fluids have different densities). Thus, we differentiate bulk (overall) density ρ_b of the soil or rock sample and, assuming pores filled with the fluid of density ρ_f and solid grains of density ρ_s, then $\rho_b = \phi \rho_f + (1- \phi) \rho_s$.

Question 1: In Fig. 5, assume that the density of water is 1 g/cm^3 and the density of soil particles is 2 g/cm^3. If the porosity ϕ of the soil is 0.4. What is the bulk density ρ_b of the soil filled with water in the glass planter?

Fig. 5. Texas bluebonnet plant (state flower) in a glass planter filled with soil and water. Photo Credit: Sabrina Ewald

Extension C:

Assume we have a sequence of three rock formations of equal thickness and equal volume (Fig. 6). If the porosities are: Layer 1 = 0.2 (20%), Layer 2 = 0.1 (10%) and Layer 3 = 0.3 (30%), what is the overall porosity in the entire volume?

Hint: If given that $V_1 = V_2 = V_3$, the volume for each layer can be represented by V. The pore space volume in the first layer is 0.2V. Repeat this reasoning for all three layers. The pore space volume of the entire sequence is then 0.2V + 0.1V + 0.3V = 0.6V. The total volume of the sequence is 3V. And the overall total porosity is thus .6V/3V = 0.2 or 20%.

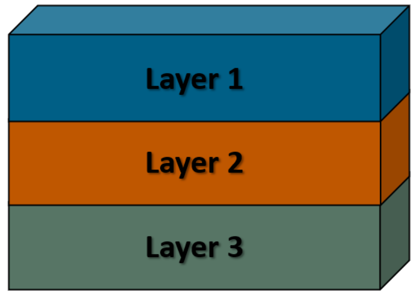

Fig.6. Sketch of three layers of rocks with different porosities in a stratigraphic sequence.
Image Credit: Sabrina Ewald

Supporting Documents:

Student Worksheet (when you click on the link, the file will automatically download to your computer)

*This activity can be adapted for different grade levels.

For Earth and Space Science and Environmental Science courses, this activity can be connected to content related to soil types, effects of compaction due to agricultural practices, and many other applications.

REFERENCES:

Image and Diagram Credits found on Student Worksheet:

1 – Source of Grain Schematics Credit: Sabrina Ewald
2 – 3D Image Credit: Maša Prodanović
3 – Aquifer Diagram Credit: https://www.usgs.gov/media/images/groundwater-saturated-zone-soilrock-below-land-surface
4 – Oil Trap Diagram Credit: https://commons.wikimedia.org/wiki/File:Fault_line.svg and Pore Space Diagram Credit: Sabrina Ewald
5 – Porosity Diagrams Credit: https://commons.wikimedia.org/wiki/File:Porosity_and_sorting.jpg