5E STEM Soil Compaction and Vehicle Mobility

(200 min; 5 days - 40 min classes)

Authors

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SUBJECT/GRADE LEVEL

Subject Area:

STEM

- Science
- Engineering
- Math

Grade Level:

Middle School (6th -8th)

Materials

Soil Coring Activity

- 3 fun sized candy bars per student group. (avoid using Twix or Kit-kat bars)
- Paper plates
- Clear straws cut into 4 pieces (slurpee/bobo size)
- Damp paper towel
- Colored pencils

Hidden Foundation:

- Various soil samples (sand, topsoil, clay, potting mix)
- Clear plastic cups or small containers
- Magnifying glasses
- Water
- Spoons/stirring sticks
- Cotton balls, small plastic beads, or other light objects

Optional Extension materials

- Soil sieves

For Cloud Dough (per group):

- cup all-purpose flour
- ¼ cup baby oil (or vegetable oil)
- Large mixing bowls
- Measuring cups
- Plastic spoons or spatulas
- Small plastic toy cars/vehicles (or pre-made simple vehicle models for testing)

Optional Extension materials

- Rolling Pin, dough rollers

For Engineering Challenge:

- Recycled materials (cardboard, bottle caps, straws, skewers, paper tubes, craft sticks, rubber bands, balloons)
- Tape, glue, scissors
- Rulers
- Stopwatches (optional)
- Ramp or incline
- Additional "soil" surfaces (e.g., loose sand, textured mat, smooth floor)

*Helpful note:

Many materials used in the following activities require recyclable or reusable materials.
Sending a message to your staff asking them to kindly collect and drop a list of recyclable items off to your classroom a week or two prior to starting could be helpful. Engineering design materials can be modified to work with the materials available.
Here is a link to some Helpful Teacher Tips and Tricks

STANDARDS

Next Generation Science Standards

- **MS-ETS1-1:** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- **MS-ETS1-4:** Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Mathematics Standards | Common Core State Standards

- ***MP.1 Make sense of problems and persevere in solving them:*** *Students need to understand the scenario, identify the relevant quantities (mass, area, gravity), and plan a strategy to solve for weight and pressure.*

English Language Arts Standards | Common Core State

- CCSS.ELA-LITERACY.SL.11-12.1.A: Come to discussions prepared, having read and researched material under study; explicitly draw on that preparation by referring to evidence from texts and other research on the topic or issue to stimulate a thoughtful, well-reasoned exchange of ideas.

ITEEA: STEL

- STEL 1 - Nature and Characteristics of Technology and Engineering
- STEL 1R - Develop a plan that incorporates knowledge from science, mathematics, and other disciples to design or improve a technological product or system.
- STEL 7: Design in Technology and Engineering Education
- STEL 7Y. Optimize a design by addressing desired qualities within criteria and constraints.

LESSON OBJECTIVE(S)

This lesson engages middle school students in understanding soil compaction as a human impact on Earth's systems, using a model-based approach with cloud dough, and culminating in an engineering design challenge focused on vehicle mobility.

Students will be able to

- Students will define soil compaction in terms of bulk density, porosity, and permeability.

- Students will analyze how human activities contribute to soil compaction and its environmental consequences.
- Students will apply mathematical concepts to calculate soil properties and vehicle pressure.
- Students will design, build, and iteratively refine a vehicle to optimize its mobility across various "soil" conditions, evaluating solutions based on criteria and constraints.
- Students will construct explanations based on evidence regarding the relationship between soil properties and vehicle performance.

CAREER CONNECTION(S)

Mentor Background: Katrina Burch is a Research Geophysicist in Cold Regions Research and Engineering Laboratory's (CRREL) Signature Physics Branch with research experience in near-surface geophysics and a specialization in seismology. Katrina has worked on varied research including: joint seismic inversions, acoustics and seismic wave propagation modeling, electromagnetic characterization, ice formation in soils, and sediment analysis. Additionally, she was selected to serve as an Acting ATD at CRREL in 2022 where she assisted the TDs in building a platform for the Congressional Increase Projects and developing a Business Intelligence model.

STEM Careers: Geologist, Geophysicist, Soil Scientist, Electrical Engineer, Mechanical EngineerChemical Engineer, Mathematician, Data Scientist, Computer Science

ENGAGEMENT - Soil Coring Activity (40 min)

Brief Description: Soil coring is an important test that is run to determine the characteristics of a given area. Soil coring will allow scientists and engineers the ability to determine where it is safe to build roads and buildings. Today, we are going to do a sample coring activity to have a similar experience to what scientists and engineers have when they are investigating the soil qualities and makeup of the soil.

Procedures:

- Provide students with the student hand-out.
- Let the candy bars sit out to warm up a little before the activity begins.
- Pass out the student activity sheet and the materials needed for the activity.
- Divide the students into groups of 3 or 4.
- Place 3 or 4 unwrapped fun size candy bars onto the small plate.
- Place your thumb over one end of the straw and then push all the way through the candy bar.
    a. Once the straw has gone all the way to the other side of the candy bar pull the straw back out.
    b. Wipe off the outside of the straw and draw what you got in your core on the worksheet.
- Continue with each of the other candy bars.
- When finished taking your core samples and your drawings please complete the rest of the worksheets questions.

EXPLORATION - Quantifying Soil Properties (60-80 min)

Brief Description: Investigate the hidden properties of soil and how human actions can profoundly change them, impacting everything from water cycles to our ability to move across the land.

Procedures:

Introduction: "Look around our environment. Think about construction sites, dirt roads and ORV (off road vehicles) routes, or even frequently walked paths. What do you observe about the ground in these areas compared to an undisturbed forest floor or garden bed? Consider how water drains, or how plants grow. Today, we're going to investigate the hidden properties of soil and how human actions can profoundly change them, impacting everything from water cycles to our ability to move across the land."

Provide students with the student hand-out.

Activity part 1: Soil Profiles and Properties Observation:

Procedure:

1. Provide groups with different natural soil samples.
2. Students use magnifying glasses, rulers, and a small amount of water to make qualitative and initial quantitative observations.

Guiding Questions for Discussion:

- What are the visible components of your soil sample? (e.g., mineral particles, organic matter, pore spaces).
- Describe the texture and color. How do these properties relate to the soil's composition?
- Predict which soil sample might have the largest proportion of empty spaces (pores) and why.
- Consider the phrase 'ecosystem services' – how does healthy soil provide benefits to living things and the environment?

Introduce the concept of bulk density and porosity as key quantitative properties of soil, explaining that they relate to how much solid material vs. empty space is in a given volume of soil.

3. Keep all the soil samples to make the soil terrains for the Engineering Design Evaluation.

Activity part 2: Measuring Soil Density and Porosity:

Students will conduct experiments to measure the approximate bulk density and water-holding capacity (related to porosity) of different soil samples. Each group will do a different sample and as a class develop a table or graph showing the comparison of each type.

Procedure (Example for bulk density and water absorption):

1. Mass of dry soil: Measure and record the mass of an empty graduated cylinder. Add a measured volume (e.g., 100 cm3) of dry soil to the cylinder. Gently tap to settle, but do not compact heavily. Measure and record the mass of the cylinder with soil. Calculate the mass of the dry soil.
2. Bulk Density Calculation: Calculate the bulk density of each soil sample:
3. Bulk Density(g/cm3)=Mass of Dry Soil(g)/Volume of Soil(cm3).

4. Water Absorption (Porosity Estimation): Slowly add a measured volume of water (mL) to the 100 cm3 soil sample until the soil surface is saturated (water no longer readily drains). Record the volume of water absorbed.

Synthesis - Math Problem 1:

If a soil sample has a total volume of 100 cm3 and absorbed 45 mL of water, what is the approximate porosity of this soil sample as a percentage? (Assume 1 mL=1 cm3). What does a higher porosity value tell you about the soil's structure?

Data Analysis:

Teams add their data to the spread sheet or graph, then through full class discussion, compare the bulk densities and water absorption of different soil types.

Discussion Questions:

- Which soil sample had the highest bulk density? The lowest? What does this tell you about the amount of solid material per unit volume?
- Which soil absorbed the most water? How does this relate to its porosity and the size/number of pore spaces?
- How might the size and arrangement of soil particles (sand, silt, clay) influence these properties?
- Ultimately, our goal is to improve mobility on arctic soils. How do you think the differences in porosity could affect how much a soil would freeze, thaw, shrink or swell?
- How would those factors affect a vehicle's ability to drive over the soil"? That is what we will be exploring in the next lesson.

EXPLANATION - The Mechanics of Soil Compaction (60-80 minutes)

Brief Description: Students will investigate the critical role of soil pore space by exploring what happens when these essential spaces are physically removed. Soil compaction is more than just squished dirt; it has cascading effects on ecosystems and human infrastructure.

Procedures:

Introduction: We've seen that soil has vital pore spaces that allow for water, air, and root growth. Now, we're going to investigate what happens when these spaces are physically removed. This process is called soil compaction, and it's a significant environmental issue.
Provide students with the student hand-out.

Activity 1: Modeling Compaction with Cloud Dough:

Cloud Dough Preparation (as a model for soil):

1. Pass out materials to each team (pair of students)
2. In a large mixing bowl, have pairs combine 1 cup all-purpose flour and ¼ cup baby oil.
3. Mix until it forms a moldable, crumbly consistency.

- Explain that this dough serves as a simplified *analogy* or *model* for soil particles and their arrangement, allowing us to manipulate and observe compaction more easily.

Cloud Dough Initial testing (as a model for soil):

1. Take one handful of cloud dough, spread it over the bottom of the container.
2. Use a hot wheel to drive the car through the sample.
    - Record your observations about how the cloud dough soil and car move.
3. Compact that layer to form a solid layer on the bottom, now drive the car over it.
    - Record your observations about how the cloud dough soil and car move.
4. Now, add another fluffy, loose layer over the solid layer, test your car and record the data.
5. Compact the layer again, and test again.
6. Your container should now be half way filled, add another handful of dough, but this time, just compact it.
7. Add the remaining dough to the container and compact it a final time, now test the car and record your observation.
    - What changed about the dough as you added each new layer?
    - Why do you think it changed and became more "road like" at the end?
8. Return your dough to the bowl and loosen, fluff it back up

Compaction Experiment and Calculations:

1. **Initial Volume & Density:** Take a section of loose cloud dough.
    a. Mold it into a precise rectangular prism (e.g., 10 cm×5 cm×4 cm).
    b. Measure its mass.
2. **Compaction:** Using a flat block or another rectangular container, apply significant pressure to compact the dough.
    a. Measure the new dimensions (length, width, height) of the compacted dough.
    b. Remeasure its mass (should be the same).

Synthesis - Math Problem 2: (Compaction Calculations)

1. You started with a cloud dough sample that measured 10 cm long, 5 cm wide, and 4 cm high.
   Calculate its initial volume in cm3.
   If the mass of the dough was 150 grams, calculate its initial bulk density (mass/volume) in g/cm3.

2. After compaction, the dough now measures 10 cm long, 5 cm wide, but only 2.5 cm high.
   Calculate its final (compacted) volume in cm3.
   Calculate its final (compacted) bulk density in g/cm3
   Calculate the percentage decrease in volume due to compaction.

Discussion Questions:

- What does this tell you about the reduction of pore spaces?
- What is the percentage increase in bulk density due to compaction?

- How does this relate to the concept of soil health?

Possible Extension:

Introduction: What is happening when the soil compresses - Imagine you're trying to build a road on top of dirt. You need to know if the dirt is strong enough to hold the road and all the cars and trucks that will drive on it without it pushing apart or crumbling.

The Direct Shear Test is like a special "strength test" for soil. Engineers take a sample of soil and then push on it in a specific way, trying to make one part of the soil slide past another. By doing this, they can figure out how much pushing force the soil can handle before it starts to break or move. This "shear strength" is super important because it helps them design roads and buildings that will stay stable and strong, even when lots of weight and pressure are put on the ground.

1. Instruct students to go to the Direct Shear Test Simulation site, provide time for them to work through the simulation and answer the questions on the students hand out.
2. Discuss the Mechanisms and Consequences:
   - Based on your observations and calculations, what physically happened to the 'pores' in the cloud dough when it was compacted?
   - Relate this back to real soil. What human activities cause soil compaction? (e.g., heavy machinery, construction, overgrazing, recreational use).
   - What are the direct consequences of soil compaction for water infiltration, root growth, and soil organisms? (Reduced water absorption, increased runoff, stunted roots, decreased biodiversity).

ELABORATE - Human Impact and Engineering Solutions (40 min)

Brief Description: Students will be taking a hypothetical road trip and need to design a vehicle to use that will effectively transverse all roadways you encounter.

Procedures:

1. Provide students with the student hand-out.
2. Explain that they will be taking a road trip and need to design a vehicle to use that will effectively transverse all roadways you encounter.
3. Direct them to Create a Car - Build & Drive Your Creation
   a. Design a vehicle for your road trip and sketch it
   b. Next, drive your vehicle online, then answer the following questions.
4. Guide students through the reflection and a discussion of their experiences
5. Model working sample math problems as needed and provide formative feedback as they work through the problems on their own. These math concepts will set the foundation work for the recycled vehicle engineering design process in the next activity and be used as an assessment of their final product.

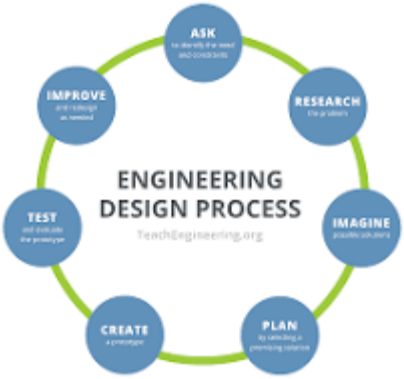
EVALUATION - Engineering Design Challenge, Terrain Traverser (90-120 min)

Brief Description: Students will take on the role of environmental engineers tasked with designing and building a prototype vehicle capable of efficiently traversing diverse 'soil' conditions, specifically loose and compacted surfaces.

Procedures:

Challenge Introduction: You are a team of environmental engineers tasked with designing and building a prototype vehicle capable of efficiently traversing diverse 'soil' conditions, specifically loose and compacted surfaces. Your design must minimize negative impact (e.g., sinking, getting stuck) while maximizing mobility.

1. **Engineering Design Process (Iterative Cycle):**



2. **Define the Problem (MS-ETS1-1):**
    - **Criteria:** Vehicle must move effectively across both loose and compacted surfaces.
        - As a teacher - define your expectation of effectively (e.g., consistent speed, minimal sinking, ability to maintain forward motion).
    - **Constraints:**
        - Available materials (recycled), time limit, size restrictions should fit completely on a 3x5 index card (so it will fit on testing surfaces), non-motorized
    - Brainstorm initial ideas, sketch proposed designs, and discuss how different wheel/track designs might interact with varied surfaces based on the modeling they completed in the previous lesson.
3. **Develop Solutions (MS-ETS1-2, MS-ETS1-4):**
    - Students use provided materials to construct their initial prototype. Emphasize that this is just the first iteration.
4. **Math it: (MP.1)**
    - ***Make sense of problems and persevere in solving them:*** *Students need to understand the scenario, identify the relevant quantities (mass, area, gravity), and plan a strategy to solve for weight and pressure.*
5. **Test and Analyze Data (MS-ETS1-3, MS-ETS1-4):**
   Set up multiple testing stations:

- The vehicle will be expected to travel down a ramp to provide the acceleration prior to traveling on the soil sample (suggested ramp: 6ft or 3 foot plastic roof gutter)
    - **Station A: Loose Soil Simulation:** Tray with loose sand or potting mix.
    - **Station B: Compacted Soil Simulation:** Tray with highly compacted cloud dough (from Explain phase).
    - **Station C (Optional):** Modify the incline ramp to be uneven terrain made from other materials (cardboard boulders/sandpaper/twigs/packing peanuts)
- **Quantitative Testing:** For each vehicle on each surface:
    - Measure the distance traveled over a set time (e.g., 10 seconds), or the time taken to travel a set distance (e.g., 50 cm).
    - Observe qualitative factors: amount of sinking, stability, ease of propulsion.
    - Record data systematically in a table.
- **Data Analysis:** Compare performance across surfaces. Discuss which design features contributed to success or failure on each surface.

6. **Optimize and Refine (MS-ETS1-3, MS-ETS1-4):**
    - Based on test results, students identify weaknesses in their design.
    - They return to their prototype to modify and improve it (e.g., change wheel size/shape, add more axles, adjust weight distribution).
    - Conduct re-tests and record new data to see if improvements were effective.
    - This iterative process is key.
7. **Present and Reflect (MS-ETS1-2, MS-ESS3-3):**
    - Each group presents their final vehicle, explaining their design choices, the challenges they faced, the modifications they made, and how their design attempts to solve the problem of navigating different "soil" conditions.
    - **Class Discussion:**
        - Which design features proved most effective on loose surfaces? On compacted surfaces?
        - How did understanding soil porosity and bulk density (from our earlier activities) inform your design decisions?
        - How does this engineering challenge connect to real-world problems caused by human impact on soil, and potential solutions?
        - What criteria would make an 'optimal' vehicle for all terrains? Is it possible to achieve true 'optimal' design for everything?

REFERENCES

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