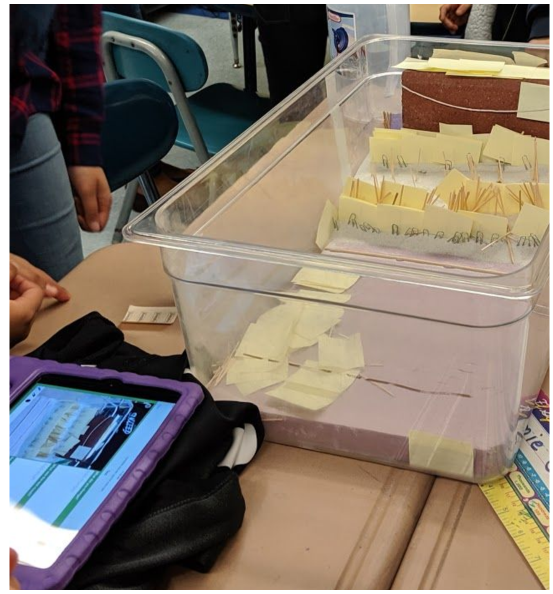

Make Way for Trains!

Holding Back Earth Materials

A Community-Connected Elementary Geotechnical Engineering Unit

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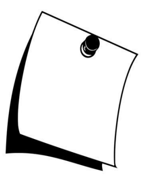
Unit Overview

In the "Make Way for Trains" unit (MWT), students explore key concepts of geotechnical engineering in the context of a train track expansion for the Massachusetts Bay Transportation Authority (MBTA): as railway corridors are widened, the sloping earth material surrounding the tracks must simultaneously support existing structures and not fall onto the tracks. Developed specifically for the Boston, Massachusetts, context, the unit begins with a look at how MBTA workers employ science and engineering for the geotechnical support for the network of tracks that make up "the T." Over 8 class sessions, fourth-grade students integrate their understanding of the engineering design process and earth science concepts, like how piles of earth materials behave with and without stabilization technologies, to generate multiple possible solutions to retain and support earth materials.



Note This unit was developed specifically for the Boston-area context and makes many references to its public transportation system. If you are in another location consider looking into your local transportation system. More than likely they will have a similar track or road expansion project from which you can draw. Any project where earth materials must be moved and supported can work.

The MWT unit addresses standards in the engineering and technology strand (3.3-5-ETS1-1, 3.3-5-ETS1-2, 3.3-5-ETS1-4, 4.3-5-ETS1-3, 4.3-5 ETS1-5), in physical science (3-PS2-1: forces), and in earth science (4-ESS2-1: earth materials into smaller pieces).

The MWT unit works well as an engineering complement to the FOSS Soils, Rocks, and Landforms[1] unit. The units are independent and can be completed in any order. This unit connects to multiple concepts in the Soils, Rocks, and Landforms unit: that earth materials are natural resources that humans use for construction and that their different properties, resulting from different earth processes, make them suitable for different uses.

This teacher guide begins with a navigation guide that overviews each day of the unit, focus questions, NGSS and Massachusetts (MA) standards, and science and engineering practices (SEPs), followed by the detailed lesson plans and required resources.

[1] https://www.fossweb.com/moduledetail?dDocName=D564298

Materials

Materials needed for this unit include large plastic containers, earth materials (including large quantities of sand and smaller quantities of other materials), and office supplies, such as sticky notes and paper clips. All materials can all be purchased at home improvement stores and through internet retailers. For a full list of material quantities and links to purchase, see the Materials spreadsheet at the end of this document.

Note about limited sand in the classroom

This unit requires a large volume of sand for inquiry lessons and the design challenge. For a class of 24 students, split into 6 groups of 4 students each, we have found teachers need about 50 lbs of sand for the entire unit, more if the students are less careful and more likely to spill it. Since it may not be possible for all teachers to procure and store that much sand in their classrooms, we have included throughout the lessons modifications for less sand, about 25 lbs for 6 groups. In general, with limited sand, students will build in their individual bins, then come to a shared classroom testing station where the sand is available to test.

Recommended Classroom Structures

Design groups

Students should work in design groups throughout the unit. We recommend assigning students to groups of three or four before beginning the unit, telling them who their groups are on the first day, and having them work in the same design groups throughout the unit.

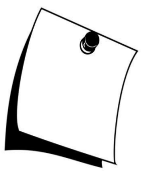
Discussing science and engineering ideas with peers can help students build knowledge in more sophisticated ways, as they articulate their own thinking, understand peers' ideas, and decide whether and how to resolve discrepancies. Students may need explicit practice with strategies for listening to each other, re-voicing what they hear, agreeing and disagreeing, asking for clarification, and justifying their own thinking. Remember that friction can be productive, literally and figuratively! Instructors should allow students to disagree about a science explanation or design solution, but help them justify their thinking and identify the source of their disagreement. Helpful resources for supporting student collaboration in science and engineering include the Talk Science Primer[2] and WGBH Design Squad[3] videos.

[2] https://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf
[3] http://pbskids.org/designsquad/

Notebooking

We recommend students document their progress as a design group in a shared engineering design notebook throughout the unit. With one shared engineering notebook, students must articulate their ideas to each other to record; this allows ideas to be debated and negotiated and requires the team to come to a (temporary) consensus.

Students build knowledge in more sophisticated ways when they have support for documenting their ideas, investigations, and design solutions. Not only does the act of documenting help students slow down and reflect on the quality of their ideas, but it also creates a record they can refer back to while designing, and use for end-of-unit reports or presentations. We recommend a multimedia engineering design notebook, so that students can store text, photos, and videos. This can be done through Google Slides, or any online resource that your students are familiar with.



Note If you have access to iPads, you can use the Design Keeper app, available for free on the Apple App Store. First, make a free account at www.designkeeper.me and then download the app from the App Store. The app provides templates for different design activities, like Ideas or Test. Each template includes fields for photos and sketches, as well as prompts for text.

Resources

All digital resources required for this unit can be accessed via hyperlinks embedded within this document. Slideshows and student handouts are included at the end of the document in PDF form.

Sharing and discussion

Throughout the unit, students should have time to discuss ideas with other groups. The goals of this time are for students to reflect on their own ideas and work, to interact with their classmates' ideas and work, and to get feedback on their work. This is an intentional time to step back from the hands-on activities and dig into reasoning. For some classes, this works best at the beginning of a session, when students haven't gotten their hands on materials yet. For others, it's a great way to close out a lesson, when students' energy is flagging and they're no longer making much progress. Some structures we recommend:

- **Share-out**: Each group takes a few minutes to describe where they are and solicit classmates' feedback. Other students ask questions and give advice.
    - *Pros*: teacher-facilitation keeps discussion on track; get to hear from all groups
    - *Cons*: if too many teams and takes too long, students may tune out; hard to concentrate when they want to be designing
    - *Good times*: Near beginning, to get feedback on plans and initial ideas before spending too much time designing; at end, to share final designs

- **Gallery walk**: Each group leaves their designs (and documentation) at their workspace and walks around to check out other designs (can do 5 minutes at each group, then all switch together). Often, groups leave feedback (e.g., on sticky notes) for other groups.
    - *Pros*: get to see all designs in a shorter time period; less likely to tune out
    - *Cons*: With less teacher oversight, some groups can get off track; takes time and practice to write useful, actionable feedback for other groups
    - *Good times*: After all groups have gotten to test and can report on their results; when students are feeling stuck or frustrated and need new ideas

- **Whole class discussion**: Teacher facilitates a discussion that can be focused on a few selected designs, a problem multiple groups are encountering, a scientific explanation that needs more time or evidence, etc. For example, one approach is to pull out 2 to 3 really different designs that are all performing well to discuss what about the designs is working (which has a side benefit of highlighting solution diversity). On the other hand, if students are frustrated with designs not working well, it can be productive to discuss as a whole class specific problems students are facing and brainstorm strategies to address those issues.
    - *Pros*: Teacher can keep discussion on track; can support deeper reasoning and connections between test results and design features; teacher can push students' thinking; can change focus of discussion if interesting ideas pop up
    - *Cons*: Groups might tune out if the discussion doesn't seem directly applicable to their design
    - *Good times*: Whenever students aren't very engaged in building and wouldn't be upset at an interruption; can be any time—beginning or end of class, after some natural stopping point, when a group has a really interesting test result that the whole class would benefit from thinking about

Navigation Guide

Learning Goal(s)
• Students will integrate their understanding of earth science concepts and the engineering design process to generate multiple possible solutions to retain and support earth materials.
Massachusetts Science and Technology/ Engineering Standards Addressed
• 3.3-5-ETS1-1. Define a simple design problem that reflects a need or a want. Include criteria for success and constraints on materials, time, or cost that a potential solution must meet.* • 3.3-5-ETS1-2. Generate several possible solutions to a given design problem. Compare each solution based on how well each is likely to meet the criteria and constraints of the design problem. • 3.3-5-ETS1-4(MA). Gather information using various informational resources on possible solutions to a design problem. Present different representations of a design solution.* Clarification Statements: ○ Examples of informational resources can include books, videos, and websites. ○ Examples of representations can include graphic organizers, sketches, models, and prototypes. • 4.3-5-ETS1-3. Plan and carry out tests of one or more design features of a given model or prototype in which variables are controlled and failure points are considered to identify which features need to be improved. Apply the results of tests to redesign a model or prototype. • 4.3-5-ETS1-5(MA). Evaluate relevant design features that must be considered in building a model or prototype of a solution to a given design problem. • 3-PS2-1. Provide evidence to explain the effect of multiple forces, including friction, on an object. Include balanced forces that do not change the motion of the object and unbalanced forces that do change the motion of the object. • 4-ESS2-1. Make observations and collect data to provide evidence that rocks, soils, and sediments are broken into smaller pieces through mechanical weathering and moved around through erosion.
Anchoring Phenomenon, Driving Question, and/or Design Challenge
MBTA Green Line Expansion Problem: The Green Line is being expanded, requiring the widening of railway corridors. As railway corridors are widened, the sloping earth material surrounding the tracks must simultaneously support existing structures and not fall onto the tracks. • What could you design to hold back the soil, rocks, and sand so that the new Green Line extension train tracks can be placed?
Meeting the Needs of Diverse Learners
• Anchor Charts, labels, consideration of groupings for ELLs and students with disabilities.
Safety Considerations
• Chaperone/parent for MBTA walk/ride. • Sand and gravel getting in eye/mouth/nose.
Field Trips and Outdoor Learning Opportunities
• Schoolyard retaining wall walk, possible neighborhood walk to MBTA station.

Lesson	NGSS Alignment	What are the students doing? Primary Learning Task	What are students figuring out? Evidence of Sensemaking
Day 1 Unit Launch	3.3-5-ETS1-1. Define a simple design problem that reflects a need or a want. Include criteria for success and constraints on materials, time, or cost that a potential solution must meet. SEP 1. Asking questions and defining problems SEP 8. Obtaining, evaluating, and communicating information	What science and engineering do geotechnical (or "geotech") engineers do? What are the problems that the MBTA needs to solve to build new tracks? • Students will take on the role of geotechnical engineers, focusing on the need to move earth's materials to construct new tracks. • Students will make observations of earth materials sliding onto roads and tracks (mudslide images). • Students will explore with sand in basins in an attempt to hold off earth materials.	Can I define the problems that the MBTA needs to solve to build new tracks? Can I gather information from photos and videos to describe the challenges of keeping earth materials from moving onto a certain location? • Engineering Notebook: Being introduced
Day 2 Inquiry Earth Material Piles	4-ESS2-1. Make observations and collect data to provide evidence that rocks, soils, and sediments are broken into smaller pieces through mechanical weathering and moved around through erosion. 3-PS2-1. Provide evidence to explain the effect of multiple forces, including friction, on an object. SEP 3. Carrying out investigations SEP 4. Analyzing and interpreting data	What do earth materials do when you put them in a pile? How do different earth materials act in a pile, and why? • Students will make observations and collect data, providing evidence that rocks, soils, and sediments are broken into smaller pieces through mechanical weathering.	Did I gather data to use as evidence to explain what earth materials do when you put them in a pile? Did I look carefully for patterns in the data in order to explain why different earth materials make steep or shallow slopes when piled? • Engineering Notebook • Data Collection
Day 3 Design Retaining Wall Intro and Mini Design Challenge	4.3-5-ETS1-3. Plan and carry out tests of one or more design features of a given model or prototype in which variables are controlled and failure points are considered to identify which features need to be improved. Apply the results of tests to redesign a model or prototype. 3-PS2-1. Provide evidence to explain the effect of multiple forces, including friction, on an object.	How can we design a wall to retain earth materials? • Students will be introduced to constraints and criteria, as they design and build a retaining wall. • Students will gather information about the "baseline solution for keeping sand off the tracks."	Did I use a model to test a prototype of a retaining wall that meets specific constraints and criteria? Can I identify and organize evidence to support why the retaining wall worked or failed? • Engineering Notebook • Sketching, taking pictures, note taking

	SEP 2. Developing and using models SEP 6. Constructing explanations and designing solutions		
Day 3.5 *Optional* Inquiry Retaining Wall Walk	4.3-5-ETS1-5(MA). Evaluate relevant design features that must be considered in building a model or prototype of a solution to a given design problem. 4-ESS2-1. Make observations and collect data to provide evidence that rocks, soils, and sediments are broken into smaller pieces through mechanical weathering and moved around through erosion. 3-PS2-1. Provide evidence to explain the effect of multiple forces, including friction, on an object. SEP 6. Constructing explanations and designing solutions	Why is it important to have retaining walls? What do you notice about the retaining walls around your neighborhood? Materials used? Potential earth materials behind it? ● Students will explore and evaluate design features through a neighborhood retaining wall walk	Can I use observations of retaining walls to compare which design features are most successful for holding back earth materials? --- ● Engineering Notebook ● Taking pictures and note taking
Day 4 Inquiry Soil Stabilization	3-PS2-1. Provide evidence to explain the effect of multiple forces, including friction. 4.3-5-ETS1-3. Plan and carry out tests of one or more design features of a given model or prototype in which variables are controlled and failure points are considered to identify which features need to be improved. SEP 3. Planning and carrying out investigations	How do geotech engineers stabilize earth materials? Which materials stabilize earth materials best? ● Students will explore soil stabilization with layers of sand separated by textile layers (materials: jersey, coffee filter, mosquito netting, etc.)	Did I test cause and effect relationships between material texture and soil stabilization using a model? Did I gather data that can be used as evidence to explain why different materials stabilize soil better than others? --- ● Engineering Notebook ● Sketching a model, keeping track of data
Day 5 Modeling Design Challenge Planning	3-PS2-1. Provide evidence to explain the effect of multiple forces, including friction. 3.3-5-ETS1-2. Generate several possible solutions to a given design problem. Compare each solution based on how well each is likely to meet the criteria and constraints of the design problem. SEP 2. Developing and using models SEP 6. Constructing explanations & designing solutions SEP 8. Obtaining, evaluating, and communicating information	How do forces act between sand grains and textile materials? What are important things to consider when solving a design challenge? ● Students will draw a model of friction between earth material particles and stabilizing materials ● Students will revisit the problem but will now allow for both soil stabilization layers and wall. ● Students will begin to plan their	Did I model how surface roughness affects the stability of earth materials? Did I share ideas for solving a design problem by sharing and discussing my diagram and materials list with my engineering team? --- ● Engineering Notebook ● Constructing explanations ● Modeling forces ● Sketching design plans

		solutions to the final design challenge.	
Day 6 Design Building and Testing	4.3-5-ETS1-3. (Plan and carry out tests of design features) 4.3-5-ETS1-5(MA). (Evaluate relevant design features) SEP 7. Engaging in argument from evidence SEP 8. Obtaining, evaluating, and communicating information	How do we conduct a fair test of our prototype? What do failure points show us about which design features need improvement? ● Students will build and test prototypes.	Can I argue to show which prototype works best to keep earth materials off of the train tracks? Did I share ideas in a class discussion of design solutions? ——— ● Engineering Notebook ● Constructing explanations and argument writing
Day 7 Design Reflection	4.3-5-ETS1-3. (Plan and carry out tests of design features) 4.3-5-ETS1-5(MA). (Evaluate relevant design features) SEP 7. Engaging in argument from evidence SEP 8. Obtaining, evaluating, and communicating information	What were the most important features of our designs? What would happen to our retaining wall if we changed just one design feature? ● Students will participate in a whole class discussion around presentation. ● Students will discuss what next steps would be. ● In groups, students will create design memos for presentation.	Did I make a claim supported by evidence from prototype testing about which design features need to be improved? Did I share the information that I have gathered on retaining wall features to support my recommendations on how to solve the green line extension problem? ——— ● Engineering Notebook ● Design Memo
Day 8 Design Feature Review	3.3-5-ETS1-4(MA). (present design solution) SEP 8. Obtaining, evaluating, and communicating information	How do engineers share their ideas through speaking and writing? ● Students will share their presentations: models, design notebooks, and drawings. ● Students will participate in a gallery walk and give feedback to each other.	Can I share my ideas on solutions for the green line expansion problem in a design conference? ——— ● Engineering Notebook ● Constructing explanations and argument writing ● Students will share their notebook sketches and writing (thinking)

Lesson 1: Unit Launch

Lesson 1 Overview

Activities

1. Read unit launch storybook (slide deck) (whole class) (10 min)
2. Introduce engineering design notebook (whole class) (10 min)
3. *Optional: Read Eleanor profile (10 min)*
4. Initial mini design task (hold back just sand, in design groups) (30 min)
5. *Optional: "Who Can Help?" activity (15 min)*

Objectives

- Students will describe the work of scientists and engineers at the MBTA, including geotechnical engineering.
- Students will make initial observations about the challenges of keeping earth materials from moving onto a certain location.
- Students will recognize the purpose of an engineering design notebook.

NGSS Alignment

3.3-5-ETS1-1. Define a simple design problem that reflects a need or a want. Include criteria for success and constraints on materials, time, or cost that a potential solution must meet.

SEPs: Asking questions and defining problems; Obtaining, evaluating, and communicating information

Materials

For each group of students

- Engineering design notebook
- Prepared construction bin:
  - Clear food storage basins
  - 12" x 10" x 1" pink foam sheet
  - 2 craft sticks
  - Enough sand for base layer (~ 2-QT)
  - 2-QT pitcher of sand (for testing)
  - 1 brick

Instructional materials (in Resources file)

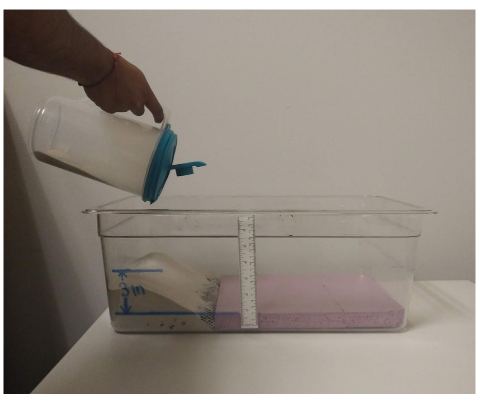
- This storybook slide deck used to introduce the unit (p. 1-11)
- *Optional: Story of Eleanor, the geotechnical engineer (can be printed for each student or group) (p. 12-18)*
- *Optional: Profiles of MBTA professionals (p. 19-23) and Who Can Help? matching game (p. 24-40)*

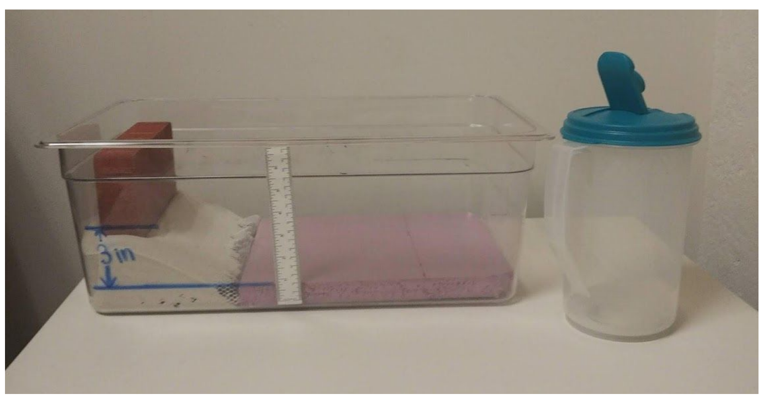
Preparation

Prepare group construction bins as shown below. The exploration task is to get the sand to support a brick at a height of 4 inches from the bottom of the basin, and to keep the sand off the craft stick tracks.

1. Place a 12” x 10” x 1” piece of pink foam on the bottom of each large clear basin (it will cover about ⅔ of the basin bottom) (don’t glue the foam to the basin; it will be removed for the inquiry lessons).
2. Create model tracks: Tape or glue two craft sticks to the foam a few inches from the empty edge of the foam or draw parallel lines with a permanent marker.
3. Fill the other side with sand to form a continuous one-inch layer, as shown below. Students will build their structures using this layer as a base. The base layer requires about 2 quarts of sand.
4. On the sand side of the basin, draw a line 4 inches (1” sand+ 3” above) from the bottom of the basin along the short edge of the basin and extending 3 inches on both long sides of the basin (as shown). This is where the houses/buildings are located that the sand needs to support.

When students test, they will pour in more sand and use a brick to model the weight of a house:





Lesson Sequence

1. Whole class: Introduce unit with slide storybook (10 min)

Use the storybook slide deck (p. 1-11) to introduce the MBTA as a client and to pose the design problem of keeping sand back off of train tracks.

2. Whole class: Introduce engineering design notebook (10 min)

As discussed in the Recommended Classroom Structures (Notebooking), student groups will share one engineering design notebook to organize pictures, video, and text to keep track of their investigations and document their engineering design process. Take 10 minutes here to introduce the notebooking system you will be using (paper notebooks, iPad app Design Keeper, Google slide templates, etc.). Talk with the students about the importance of notebooking and the kinds of things that are helpful to document, like test results or theories from inquiry lessons.

3. Optional: Read Eleanor (geotechnical engineer) profile (10 min)

Have students read this profile (or in slides, p. 12-18) of a (fictional) engineer at the T. Students can read and then discuss in design groups, read individually and then discuss as a class, or do as a whole class read aloud; whichever makes the most sense for your class. Discuss with the whole class to ensure students understand the problem Eleanor faces. (This can also be done on another day, or as part of a literacy time.)

4. Initial problem exploration (30 min)

Show the whole class the construction bin setup and set a goal for students' exploration: support the model building (brick) at the height of the line while keeping the sand off the tracks. At this point, do not provide any building materials (like sticky notes or toothpicks).

The purpose of this initial exploration is to show students WHY geotechnical engineers need to build something to hold the sand back. It's also a great way to see how and why the piled sand collapses with the building, which will help students when they build their retaining wall solutions in a few lessons. Students should be getting a feel for the problem and how hard it is, and how/why an unsupported pile of sand fails, before they build anything. They are not actually trying to solve the problem this day.

Example introduction for students:
This activity is an exploration of why geotechnical engineers are needed--because sand doesn't stay in place on its own! So we need to build something to keep it where we want it.

Give students time to try to shape the sand into the desired form with their hands. When they feel ready (or after some limited time, since they may never feel ready!), have them place a brick on top, gently shake/vibrate the bin (to model train rumbling), and take a picture or make a sketch. They can take some notes about what happened and any ideas about what they would want to build to keep the sand off the tracks.

Shaping the sand to support a brick should be *difficult*, but it won't be impossible. If students successfully get the brick to stand level at 3 inches, shake the bin from side to side and ask if they'd be comfortable living in that house. Later in the unit, they will build a structure to stabilize the sand.

5. Optional: Who Can Help? Game (15 min)

Print a copy of the "Who Can Help?" slides (p. 24-40, Resources) for each group (you can print multiple slides per page so they look more like playing cards). Have the students discuss the cards within their design teams and match up each problem (like station flooding or train derailment) with an MBTA professional who could help solve the problem.

Note about limited sand in the classroom

If you don't have enough sand for all groups to work on the exploration at the same time, you can set up two construction bins and rotate groups through them. They may only need 2-3 minutes to attempt to shape the sand, and another minute or two to document their attempt.

Groups not at the construction bins can either:

- Play the "Who Can Help?" game described above.
- Record initial ideas about the design challenge in their team engineering design notebook while the two groups do the initial challenge.
- Read the profile of "Eleanor the Geotechnical Engineer" in groups and discuss (if not done as a whole class).

Lesson 2: Earth Material Piles

Lesson 2 Overview

Activities

1. Introduction (whole class) (5 min)
2. Guided inquiry stations on material piles, with documentation (design groups) (30 min)
3. Discussion (whole class) (15 min)

Objectives

- Students will predict how different earth materials will behave when put in a pile.
- Students will recognize that all earth materials make a *slope* when piled up.
- Students will observe piles of different earth materials and describe how their slopes differ.
- Students will generate explanations for why some earth materials make piles with steep slopes and some make piles with shallow slopes.

NGSS Alignment

4-ESS2-1. Make observations and collect data to provide evidence that rocks, soils, and sediments are broken into smaller pieces through mechanical weathering and moved around through erosion.

3-PS2-1. Provide evidence to explain the effect of multiple forces, including friction, on an object. Include balanced forces that do not change the motion of the object and unbalanced forces that do change the motion of the object.

SEPs: Planning and carrying out investigations, Analyzing and interpreting data, Constructing explanations

Materials

For each station

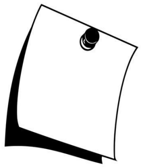
- 1 large, clear basin with tape rulers on side - one per group
- 1 quart earth material (~ half the plastic lidded container)
  - Sand, gravel, soil, aquarium pebbles
- 3 small paper cups
- 1 cardboard circle, 7” diameter (cake round)

For each design group

- Engineering design notebook

Instructional materials

- Photo of sand dunes national park



Note on stations Although we refer to stations in this lesson, the process often works better if groups stay in one location with their bin setup and the earth materials are rotated to each group. This is particularly true in classes where some groups are faster than others, so groups aren't waiting to switch--as soon as another material becomes available they can use it.

Lesson Sequence

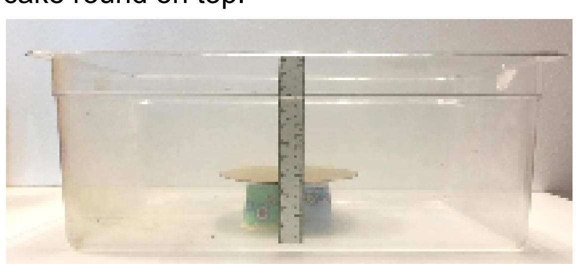
1. Introduction (5 min)

- Review the conclusions of Lesson 1:
    - We learned about the MBTA's plan to build new train tracks. They need to move a lot of earth material out of the way before the train tracks can be built. What problem do they have with earth materials? (*If you read the Eleanor story, you can root this intro in her context*).
    - What happened when you tried to pile the sand on one side of the bin and put a weight on it?
- To design something to keep earth materials like sand off the new Green Line tracks, it's important to understand how earth materials function--what they act like. Today, we're going to investigate: ***How do different earth materials act in a pile, and why?***
- Show a photo of sand dunes or similar landforms (photo of sand dunes national park). Ask what students notice about the dunes. **Why are they shaped the way they are? Would they have that same shape if they were made of gravel, or soil, or pebbles?**

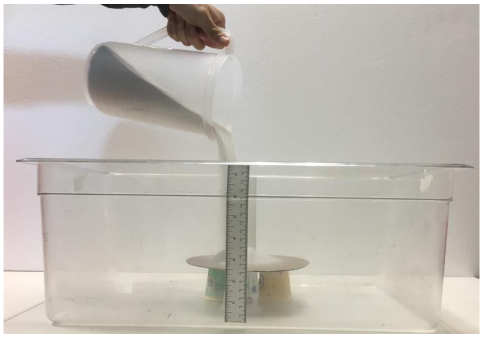
2. Guided inquiry on slopes (30 min)

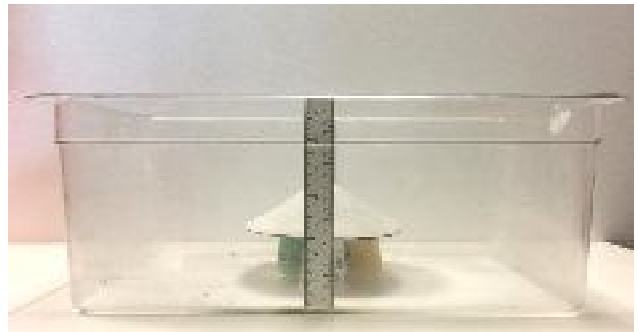
Each station will have about 1 quart of one earth material type (soil, sand, gravel, or aquarium pebbles). Students will rotate around in their groups to each station (or materials will rotate to them). With each material, they will try to make the steepest pile they can on top of a circular base. The base will be propped up on three small paper cups. When their pile is as steep/tall as they can make it, they will take a picture and record the approximate height of the pile using the ruler on the side of the bin.

- Demonstrate one trial of the experiment (5 min)
    - Make the circular base: Inside a clear basin, place three paper cups face down and place a 7" cake round on top.



    - Have students predict what the shape will be BEFORE you pour the sand/soil/gravel onto the disk (could draw options on the board and have them vote, or just ask for ideas). Then pour the material out, attempting to make the steepest pile possible. Describe the difference between a *steep* and a *shallow* slope.





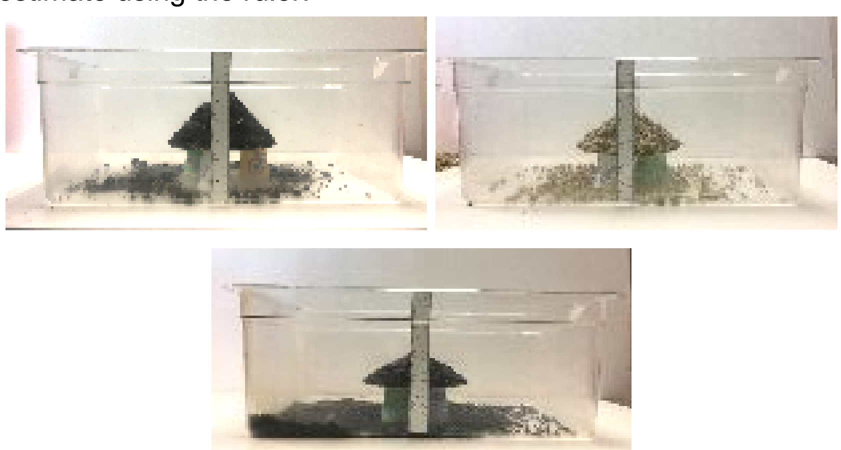
- ○ Demonstrate how to measure the height of the pile using the ruler tape on the side of the bin.

Note Because each pile will start at the same height, it's not necessary to subtract the height of the platform. It will work to write down "5 inches" or "6 inches" for the height, even though the pile begins on the cardboard base. If you want to emphasize measuring and math, then you could have students subtract the height of the base.

- ○ Discuss the connection between height and steepness of the angle--that steeper piles will be taller. We really care about how **steep** a material is, but when we are working with piles that all have bases of the same diameter, it's easier to measure and compare the height. With identical bases, taller means steeper.

Rotating slope inquiry stations in design groups (25 min)

- Have student groups go to their first stations. Instruct groups to repeat the piling and measuring ideally twice for each material (if one group is very slow, it's fine to only do it once, since the class will have enough data points). They should take a picture of at least one trial of each material and record, in their engineering design notebooks, the height they estimate using the ruler.



Soil (Top left); Gravel (Top Right); Aquarium pebbles (Bottom middle)

3. Whole class discussion (15 min)

Note Student reasoning is more important than the actual numbers measured. If there is not much time, prioritize spending time discussing WHY the materials make piles and WHY the different materials make piles with different steepness.

- Share results. You could do this qualitatively, and just have groups report which material they found was the tallest, or create a whole-class table with groups' results. It might look like this:

Material	**Measured heights (inches)**	**Average/typical height (inches)**
Sand	4.5, 5.5, 5	~ 5 inches
Soil		(probably tallest)
Gravel		
Aquarium pebbles		(probably shortest)

  - How similar were the slopes measured by different groups?
  - If we look at the most "typical" results, which earth material made piles with the steepest slope?
  - Which earth material piles were the shallowest?
  - **Why do the different materials make different slopes?**
  - **Why might ____ (usually soil) make the steepest slope and _____ (usually sand) make the shallowest slope?**

- Ask students to observe the properties of the grains of each earth material and describe the differences they observe between the different earth materials. Support students' reasoning about which materials make piles with steeper or shallower slope, *and **why***. Lead a whole-class discussion of observations and reasoning. Don't worry about introducing technical terms that the students are not comfortable with. It's more important that they begin to understand what's happening with the grains of material than using or remembering words like "gravity" and "friction."
  - **Why did the earth material slide off/fall down?**
    - *Gravity is an important force in erosion; the attractive force of the very massive earth is pulling down on all of the grains. In student language, they may talk about the pieces being heavy and falling or sliding off. Sometimes the word "gravity" connotes planet-scale forces for students and is less helpful in this context. If students bring up gravity, have them explain WHY gravity matters here.*
  - **What prevented some of the earth material from sliding off?**

        - *Friction between the different earth materials. In student language, the particles/grains of sand or rocks push against each other and the ones on the bottom stop some of the ones on top from falling down/sliding off.*
        - *Balance of forces: gravity (pulling down to earth), friction (roughness/bumpiness of the rocks/sand/soil help push on each other and keep them up).*
    - **How might the size and shape of the little pieces (grains) of each earth material affect the slope they take on** (whether it's steep or shallow)?
    - **How are the grains of the earth material interacting with each other?**

It's great if students get to talking about gravity and friction from prior knowledge, but the concepts are more important than the terms, and the terms can often get in the way of the ideas. In non-technical language, we might expect students to talk about how the sand is rough which makes it harder for the other sand pieces to fall off it (starting to get at the idea of friction)--go with whatever language makes sense to them.

- Connect back to the MBTA track expansion problem. There is earth material in the place where new tracks need to go. If you wanted to move those earth materials by pushing them into a tall, flat tower, could you? Help students see that all earth materials make a slope when piled up. Some earth materials make steeper piles; some make shallower piles. But they all make piles. This is why geotechnical engineers need *retaining walls*.
- In the next lessons, students will learn about and build retaining walls to keep earth material piles out of the way.

Resources & extension activities

- Sand dunes in California
- Antlion larvae (worm-lion) utilizes the angle of repose to build pits to trap ants (their prey). They throw soil out until they reach the angle of repose. When an ant wanders into the pit, the added weight causes the soil to start sliding so the ant can't climb out. Additionally, the larvae will throw sand onto the side to make it start sliding intentionally. The end of this video has a vivid visualization of the ant trying to escape and the walls just sliding out from under them.

Lesson 3: Retaining Walls Design Challenge

Lesson 3 Overview

Activities

1. Review & Introduction to retaining walls (10 min)
2. Retaining wall design challenge (design groups) (25 min)
3. Discussion (10 min)
4. Clean up (5 min)

Objectives

- Students will observe pictures of multiple retaining walls and make generalizations across them.
- Students will discuss what makes retaining walls fail.
- Students will (informally) plan retaining wall designs.
- Students will collaboratively build and test prototypes of their design solutions.
- Students will discuss their prototypes and test results as a whole class.

NGSS Alignment

4.3-5-ETS1-3. Plan and carry out tests of one or more design features of a given model or prototype in which variables are controlled and failure points are considered to identify which features need to be improved. Apply the results of tests to redesign a model or prototype.

3-PS2-1. Provide evidence to explain the effect of multiple forces, including friction, on an object.

SEPs: Developing and using models; Constructing explanations and designing solutions

Materials

For each design group

- One prepared construction bin (see Preparation)
- Small slips of paper (roughly 1.5” x 2”) - mini sticky notes
- Toothpicks
- Paper clips
- 3 inches of masking tape
- Engineering design notebook

Limited sand modification

- Two shared construction bins at testing stations (see Preparation)

Preparation

Construction Bins (one per team)

- Place 10”x12” foam piece (with model train tracks) on one side of the bin.

> Do not glue the foam into the bin, it needs to be removed for Inquiry days! Also, this is the first of 3 days that students will use their construction bins with building materials. The foam is particularly susceptible to damage. Ask students not to push paper clips or toothpicks into the foam so that it can be used for the design challenge again and again.

- Fill the other side of the bin with sand, so that it forms a 1” layer, even with the foam.
- Draw lines on the outside of the bin to mark where the “building” (brick) should be: 4” from the bottom of the basin (3” from top of foam/sand layer) and 3” away from the back side, as shown.
- Provide each group a 2-QT container of sand (1 pouring container) and one brick for testing.

> ## Note about limited sand in the classroom
>
> If you have limited sand, prepare each group’s construction bin with a 1” base layer of sand, but do not provide them with a pitcher or brick. Instead, set up two testing stations. At each, place one brick and one 2-QT pitcher of sand. Students can plan and build their structures in their team’s construction bin at their workspace. When they are ready, they can come to the testing stations to add sand, test their retaining wall with the weight of the brick, and shake to simulate train rumbling.

Lesson Sequence

1. Review 7 Introduction to lesson (10 min)

- Review Lessons 1 & 2
  - To remind students of the problem, you can use the storybook launch slides (p. 1-11)
    - What happened when you tried to pile the sand on one side of the bin and put a weight on it?

- Last time, we saw that all piles of earth materials have slopes--they form piles. For MBTA engineers to keep the earth materials away from the tracks, they need to build something to hold back the earth.
- Today, we'll learn about and build structures engineers build to keep back sand, rocks, and dirt

- Intro to retaining walls
  - Show and discuss the Intro to Retaining Walls slides (p. 41-48), pausing to let students observe and make sense of the pictures.

2. Retaining wall design challenge (25 min)

Note You can frame the task as generating a "baseline solution" for the final design challenge. In other words, the purpose of today is to get a record of what can be done with just a retaining wall, which students will try to beat in the unit's final design challenge, after they learn more about geotechnical engineering and stabilization techniques.

Distribute or display the design brief (p. 22 here or p. 50 in Resources) and show the testing bins. Tell students:

- Today, we're going to try again to keep the earth material off the tracks, but this time, you'll be building retaining walls to help. Every group gets a bin with a piece of foam and a layer of sand. The foam represents concrete, where the train tracks are. The layer of sand is the foundation for the structure that you build.
- Instead of building with concrete or wood, we're going to build models of retaining walls using paper clips, toothpicks, and pieces of paper.
- The walls you'll make need to keep sand up to the marked line and hold up this model house. The walls also need to stay up when the train comes by and shakes the ground--we'll model this by gently shaking the bin.
- You have this whole container (2 quarts) of sand to use. You can choose how to use it as a group--some groups may want to have their retaining wall(s) all the way built, then add the sand. Some groups may choose to build a little bit, add some sand, then add more structure.

Note about limited sand in the classroom

If you are using testing stations, students will build in their own construction bins, then perform the same test described (add brick, shake the bin) at the station. Tell students: *"When you are ready to test your design, you will come to the testing station. Here you get a whole container (2 quarts) of sand to pour into the bin and a brick to place on top. You will observe how well your design supports the weight, then gently shake the bin to model trains rumbling by. When you're done documenting the test, you will pour out the sand so another group can test and go back to your place to build a new design."*

Mid-Unit Design Brief

Goal: Design, build, test, and iterate on a retaining structure that keeps sand away from the model train tracks, allows the sand to support the weight of a model building, and stays up when the train goes by.

Criteria:
Your retaining structure MUST:

- Keep all sand off of the pink foam and model train tracks.
- Withstand "train rumbling" (shaking the basin).
- Keep the sand stable enough that it can hold up a model "building" (brick) at the marked location.
  - The building MUST stay level, so it does not tilt.
  - The building is located 4 inches above the base of the basin (3 inches above the foam/sand layer) and 3 inches away from the short side.

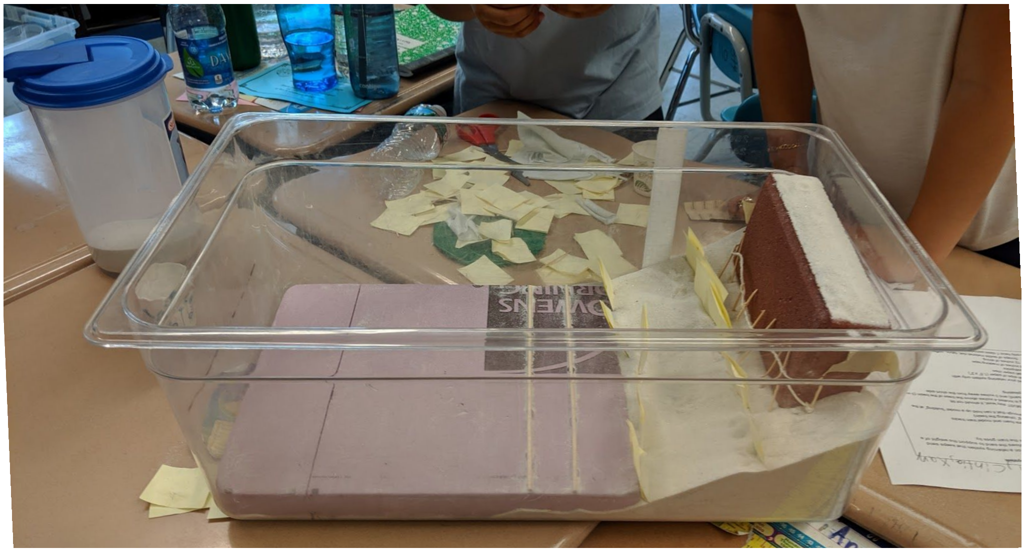
Constraints:

- You may build your retaining structure only with:
  - Small slips of paper (1.5" x 2")
  - Paper clips
  - Toothpicks
  - 3 inches of masking tape
- You only have 25 minutes to build your structure

DO NOT push toothpicks or paper clips into the pink foam--that is too close to the tracks to build a retaining wall. (It also ruins the foam)

MAKE SURE YOU RECORD everything in your design notebook.

Example from another class:



Design process You can choose to be more prescriptive about the design process if you think it would benefit your students. This could range from reminding students of the general design process activities (planning [which could include sketching, individually or as a group], building, testing, and revising based on the test), to explicitly asking groups to record ideas from each group member before beginning to build). For this task, with novel building materials, students likely need to manipulate the materials in their hands to generate ideas, so it can be helpful to provide materials while they make design sketches. If extra steps are required, students will need two class periods to do the challenge.

Notebooking As you circulate to check in on groups, encourage recording their ideas and tests using their design notebooks. Many groups take pictures or videos but feel too rushed to write anything, but then the pictures are not useful in the future. Encourage students to refer to their notebooks when explaining ideas.

3. Discussion (10 min)

Consider cleaning up before the discussion, to provide an authentic reason for complete documentation (students will then have to discuss their design using only their notebook). (If they are sharing sand, then pictures are a must, since they will not have a completed design at the end.)

If students cannot take pictures of their designs, then have students walk around and see each other's designs BEFORE they clean up (and consider showcasing designs during testing).

Project a few groups' notebooks and have them discuss their **process** for generating an idea, testing it, and especially how they changed it over time. (Rather than focusing on the wall they made). Highlight the benefit of the notebook in capturing all that information, and nudge groups who forgot to record to add more information next time.

- Perhaps choose two very different solutions to show the whole class--and highlight the different ways the groups came up with their ideas.
- The goal is give good notebook examples and to start the discussion

Potential discussion topics, depending on what students created:

- *Why do you think ___ walls performed better than ___ walls?*
- *Were some walls better at holding up more weight and other walls better at resisting the shaking?*
- *Did your walls fail in the same way real retaining walls failed (in the pictures)?*
    - *WHY did the wall fail like that? What is happening? What parts of the wall is the sand pushing on?*
- *Did one big wall or many small walls (like steps) work better in this case?*
- *What retaining wall design recommendations can we think of based on our class walls?*

4. Wrap up & clean up (5 min)

Tell students that next class, they will learn about a method geotechnical engineers use to make piles of sand stand up higher and stronger, so retaining walls are better able to hold the material back.

(Optional) Lesson 3 Extension: Retaining Wall Walk

Lesson 3 Extension Overview

Activities

1. Review & Introduction to lesson (10 minutes)
2. Retaining wall walk (physical or virtual) (30 minutes)
3. Whole class discussion (10 minutes)

Objectives

- Students will compare and contrast different retaining walls in their neighborhood.
- Students will generate explanations of how retaining walls work.
- Students will generate explanations of why some retaining walls fail.

NGSS Alignment

4.3-5-ETS1-5(MA). Evaluate relevant design features that must be considered in building a model or prototype of a solution to a given design problem.

4-ESS2-1. Make observations and collect data to provide evidence that rocks, soils, and sediments are broken into smaller pieces through mechanical weathering and moved around through erosion.

3-PS2-1. Provide evidence to explain the effect of multiple forces, including friction, on an object. Include balanced forces that do not change the motion of the object and unbalanced forces that do change the motion of the object.

SEPs: Asking questions and defining problems; constructing explanations and designing solutions

Materials

- *Optional:* Measuring tape or ruler (to measure the height of retaining walls)
- *Optional:* Camera (or phone/tablet with camera) to take photos of retaining walls

For each student

- Observation sheet (or p. 52, Resources) and clipboard for taking notes while on the walk

Instructional materials

- Retaining walks in the Boston area: Sheridan Street in Jamaica Plain; Curley School; Russel School; Boston Avenue, Medford; Underpass near the Hatch Memorial Shell

Lesson Sequence

1. Review & Introduction (10 min)

- Review the conclusions of Lesson 2:
  - What happened when you made a pile of earth materials? Was the slope of the pile you made for the three different earth materials the same? Why do you think the slope was different?
  - Connect back to the MBTA track expansion problem. There is earth material in the place where new tracks need to go. If you wanted to move those earth materials by pushing them into a tall, flat tower, could you? Help students see that all earth materials make a slope when piled up. Some earth materials make steeper piles; some make shallower piles. But they all make piles. This is why geotechnical engineers need retaining walls.

- Introduce the Focus Questions: *Where in our neighborhood do we see retaining walls and how are they similar or different to each other? What may cause retaining walls to fail?* The goal of today's investigation is to find out what different types of retaining walls look like and investigate why some retaining walls fail.

2. Retaining wall walk (30 min)

- Let students know that they will be taking a walk around their neighborhood to observe different retaining walls.
  - Show students of retaining walls like the ones they can expect to see in their neighborhood. (You can use the Lesson 3 Intro to Retaining Wall slides).
  - Discuss with students what observations they might make about the walls. Materials used? Potential earth materials behind it? Successes/Failures (Do some walls look like they are bowing/cracking, crumbling)?
  - Demonstrate how students may record these observations in their observation sheets.

- Take a walk around the school or through the neighborhood to look for examples of retaining walls.
  - Students may sketch on their observation sheets or take photos of the different retaining walls they see. (Or the teacher may be the one designated to take photos.)
  - Before going out, or after coming back, can also use Street View in Google Maps to take a virtual walk in students' own neighborhoods
  - (One good example: Sheridan Street in Jamaica Plain) (Other examples: Curley School; Russel School; Boston Avenue, Medford; Underpass near the Hatch Memorial Shell)

3. Whole class discussion (10 min)
    - Have groups share results: Facilitate sharing from notes and/or images of the different retaining walls students saw on the walk
        - What do they look like?
        - How well are they performing?
        - What types of materials might they be holding back?

    - Conclude by connecting back to the MBTA track expansion problem. There is earth material in the place where new tracks need to go. You can use a retaining wall to hold those earth materials in a tall, flat tower. Retaining walls can be made out of different materials. However, not all retaining walls are successful and engineers need to find ways to build retaining walls so that they don't fail. In the next class, you will look at different ways to design a retaining wall.

Resources

- Sheridan Street in Jamaica Plain, where it's easy to see retaining walls holding back earth material in residents' front yards.

Lesson 4: Soil Stabilization with Textile Layers

Lesson 4 Overview

Activities

1. Intro: Reminder of retaining walls, preface today's work (5 min)
2. Part 1: Test strength with NO layering (design groups) (2 minutes)
3. Part 2: Comparing layer material (design groups) (18 min)
4. Part 3: Comparing layer thickness (design groups) (15 min)
5. Discussion (8 min)
6. Clean up (2 min)

Objectives

- Students will compare the properties of materials used to stabilize soil.
- Students will compare the effects of layer thickness and different materials on the stability of sand towers.
- Students will construct explanations for why layer thickness and varying layering materials affects soil stability.

NGSS Alignment

3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

3.3-5-ETS1-4(MA). Gather information using various informational resources on possible solutions to a design problem. Present different representations of a design solution.

4.3-5-ETS1-5(MA). Evaluate relevant design features that must be considered in building a model or prototype of a solution to a given design problem.

3-PS2-1. Provide evidence to explain the effect of multiple forces, including friction, on an object. Include balanced forces that do not change the motion of the object and unbalanced forces that do change the motion of the object.

SEPs: Obtaining, evaluating, and communicating information, Developing and using models, Analyzing and interpreting data, Constructing explanations

Materials

For each design group

- Engineering design notebook
- One empty basin
- Sand in 2-QT plastic pouring container
- 1 prepared clear plastic square tube with ½-inch markings

For the class

- 40 pre-cut 3.75-inch squares of each of 3 materials
  - Fabric, wax paper, mesh/netting

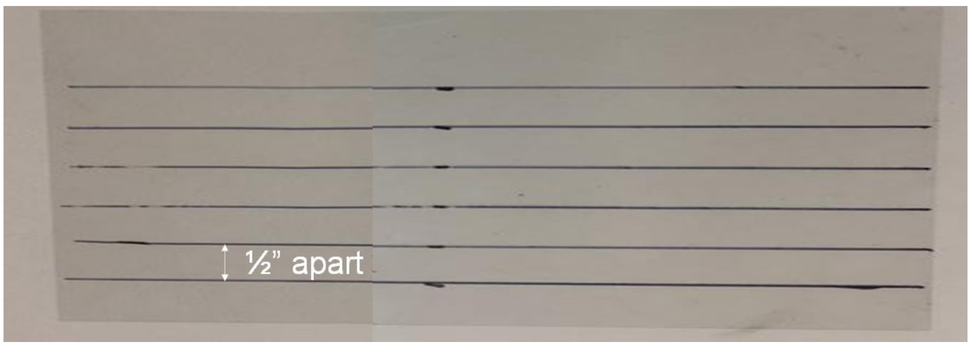
Instructional materials

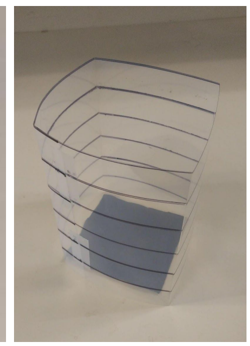
- Video: Better Sand Castles in 80 Seconds (**6:42-9:01**)

Preparation

- Prepare textile squares: Make at least 13 squares of each material: mesh, wax paper, and fabric. Groups will rotate testing the different materials.

- Prepare one transparency-sheet-square-tube for each group. Draw 8 parallel lines one half inch (½”) apart going the long way down an 11”x17” transparency sheet. Score and fold the sheet into a square tube about 4” per side (they should fit around the cut out squares easily).





Lesson Sequence

1. Introduction to soil stabilization (5 min)

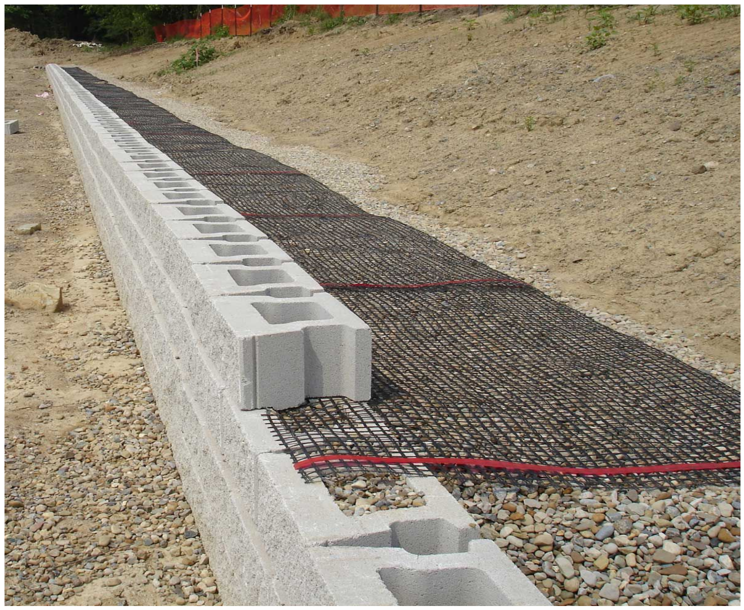
Remind students of previous work

- *Last class, we talked about retaining walls* (can show a picture if it’s been a while):

- *And we attempted to build one in our basins to keep sand off the track, but it was hard!*
- You can show a few examples of notebook pages from last class
- ***Today, we’re going to learn about a method geotechnical engineers use to “stabilize” earth materials like sand.***

Introduce soil stabilization with video

- Watch a clip from this video: Better Sand Castles in 80 Seconds (**6:42-9:01)**
- Discuss:
  - How are earth materials like sand and pebbles similar to ping pong balls?
  - How does sandpaper or screen stabilize the sand castle?
- WARN Students that they won't be able to use water like in the video, so theirs won't look exactly the same as the video
- One way engineers make the pile of dirt or sand stronger is by adding layers of textile material between layers of earth material. Then the wall can hold back much more material. It would look something like this:



Over steps 2, 3, and 4, students work through the inquiry activities to explore textile material layering. Detailed instructions on layering can be found below, on pages 33-34.

2. Part 1: Test strength with NO layering (2 min)

- Each group gets a square tube with lines, clear basin, and container of sand.
- (Demo this if necessary first) Have students first fill up their clear tube to the 4" mark (top line) with **JUST sand**. Then remove the square tube--the sand will fall down. Have students **press down on the top of the pile with their hands** to see how strong it feels. Demonstrate how to read the height of the pile through the clear side of the bin using the measuring tape on the side. (There are more pictures of this procedure, including with layers, at the end of this document.)

- If necessary, demonstrate how to take a picture of the final pile and record the estimated height in their engineering design notebooks.
- Ask students rhetorical/reminder questions: When we add the layers next, are we hoping for the sand to feel stronger or weaker? For the final pile to be taller or shorter?

3. Part 2: Comparing layer thickness (18 min)

- *Focus Question: How does layer thickness affect the soil stabilization?*
- Now, groups will alternate pouring in sand with layering materials, like a layer cake.
- Groups should have a single type of textile material for this part, with at least **13 squares** of that material
- Instructions: *First, you will try adding a layer material every ½ inch (one layer at every line, 7 layers of textile material total). Lift off the clear square tube and press down on the pile. Does it feel stronger than it did without layer materials? Record a picture and the final height.*
- *Once you do every ½ inch, you'll test and document other layer thicknesses: What happens when you only put a textile layer every 1 inch? (every other mark, for a total of 3 textile layers) What about every ¼ inch? (textiles at every mark and halfway between the marks, a total of 13 layers)*

Notebooking As you circulate to check in on groups, encourage students to document their inquiry with a picture or sketch of each trial, the final pile height, and a note about how it felt to push on the pile.

4. Part 3: Comparing layer materials (15 min)

a. *Focus Question: How does layer material affect the soil stabilization?*
b. Place piles of material squares in a shared location and groups can go collect a pile of squares to test out, returning the squares when they are done and choosing a new stack.
c. Instructions: *For this part, you'll repeat the layering procedure, but this time keeping the thickness the same and trying out at least 1-2 other materials. You can do ½ inch layers or some other thickness, based on your results from the previous part. But make sure you are consistent, so comparisons are fair.*

Notebooking As you circulate to check in on groups, encourage students to document their inquiry with a picture or sketch of each trial, the final pile height, and a note about how it felt to push on the pile.

5. If time: Free inquiry

a. If groups have other ideas for other explorations they are curious about, let them explore! Just make sure they record everything they try in their notebooks.

- For example, in other classes, students have wanted to try multiple layers of textile materials between each layer of sand, combining multiple kinds of textile layers, and different thicknesses of sand at the top and bottom of the tube.

6. Discussion (8 min)

a. Show pictures, sketches, or notes from a few groups' notebooks (the more complete ones) and have them discuss their process and ideas, using the notebook as evidence. Highlight the benefit of the notebook in capturing all that information, and nudge groups who forgot to record to add more information next time.

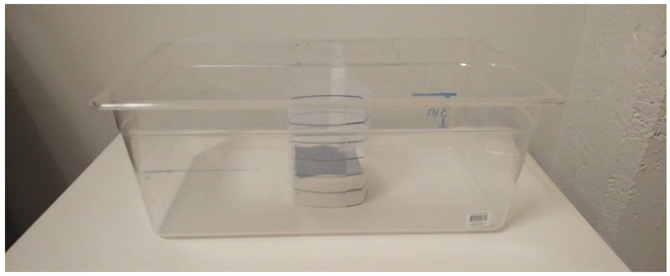
b. Potential discussion topics, depending on what students created:
   - Why does putting those layers in affect how much weight a pile of sand can hold?
   - Which layer thickness (¼", ½", 1") resulted in the highest pile?
   - Which materials worked well? Which ones didn't work as well? Why do you think so?
   - Which layer thickness felt most stable when you pushed down on the pile?
   - Why do you think the piles with different layer thickness had different final heights?
   - What do you think is happening to the sand particles?

7. Wrap up & clean up (2 min) [OR clean up before discussion]

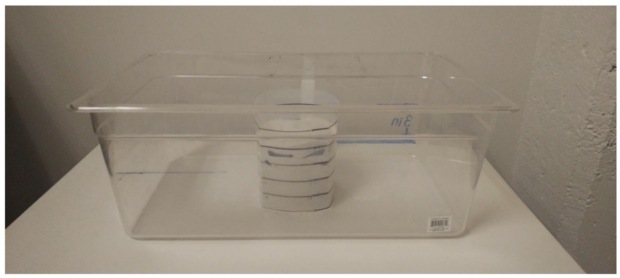
a. Tell students that next time, they will get to put together what they've learned about retaining walls and soil stabilization to design a full stabilization system for the MBTA.

Detailed instructions for layering sand and textile materials:

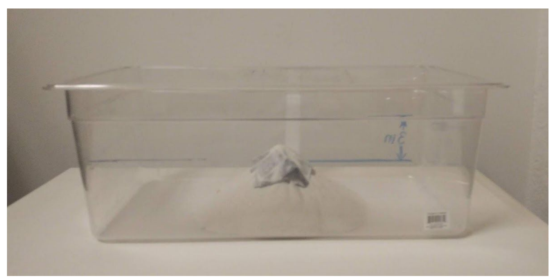
1. Place the clear square tube in a basin or other clear plastic container to contain spilling sand.
2. Pour ½” of sand into the tube (up to the first mark). Level the sand a bit.
3. Place a square piece of fabric/wax paper/mesh on top of that layer of sand.



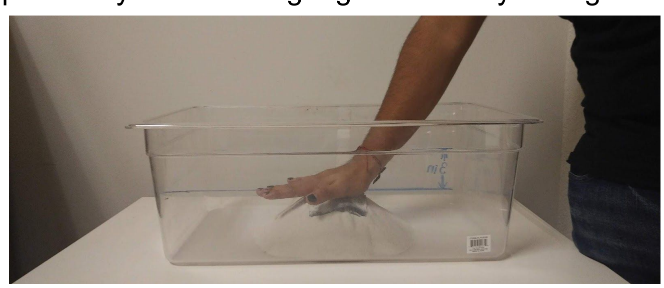
4. Repeat steps 2 and 3, adding more layers of sand and textile until the tower is 4 inches tall.



5. Slowly lift the tube off of the tower. Sand will slide out to the bottom of the basin.

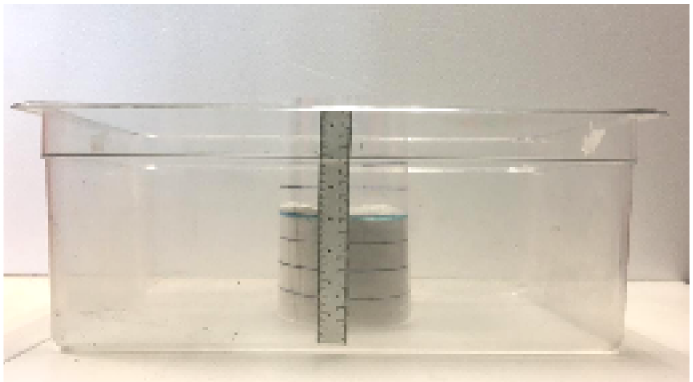



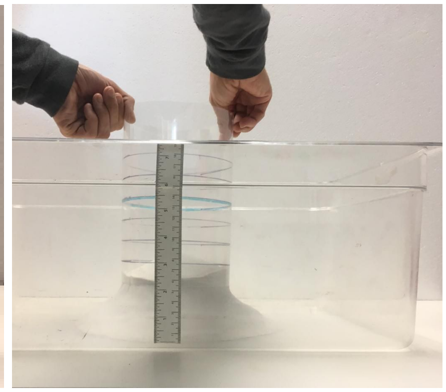
6. Push down on the pile with your hand to gauge its stability/strength.

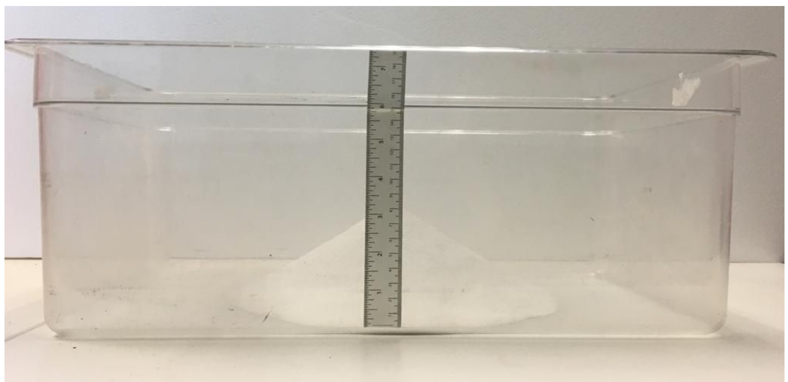


7. Look through the side of the basin to estimate the height of the pile. Record the height.
8. Take a picture or make a sketch of the pile. If it’s helpful, describe what it felt like to push on the pile.

In Part 1, without textile layers (sand alone), the sand will spread out farther and compress more when pressed.







Lesson 5: Friction Modeling & Final Design Planning

Lesson 5 Overview

Activities

1. Model friction between earth material particles and stabilizing materials (design groups + whole class discussion) (25 min)
2. Review & introduce final design challenge (including soil stabilization layers) (5 min)
3. Plan for the building of retaining system (design groups & whole class) (20 min)
    - Planning in groups, sharing ideas between groups, revising in groups

Objectives

- Students will construct explanations for why layers of materials affect soil stability.
- Students will use evidence from observations to explain how friction affects soil stability.
- Students will define the design problem, including criteria and constraints.
- Students will generate multiple possible solutions to retain and support earth materials out of the way of model train tracks.
- Students will communicate their reasoning about possible design solutions.
- Students will collaboratively make a plan for constructing a prototype of a design solution.

NGSS Alignment

4.3-5-ETS1-5(MA). Evaluate relevant design features that must be considered in building a model or prototype of a solution to a given design problem.

3-PS2-1. Provide evidence to explain the effect of multiple forces, including friction, on an object. Include balanced forces that do not change the motion of the object and unbalanced forces that do change the motion of the object.

3.3-5-ETS1-1. Define a simple design problem that reflects a need or a want. Include criteria for success and constraints on materials, time, or cost that a potential solution must meet.

3.3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

SEPs: Developing and using models, Constructing explanations & designing solutions, Engaging in argument from evidence, Obtaining, evaluating, and communicating information

Materials

For each design group

- Engineering design notebook
- Samples of textile materials
- *Optional: Hand lenses*

Instructional materials (in Resources file)

- Sand Grain Forces Modeling slides (p. 53-62 in Resources)
- Unit Review and Design challenge slides (p. 65-70 in Resources)
- Sand grain forces handout (1 per student) (p. 64, Resources)
- Final Design Brief (or p. 69, Resources)

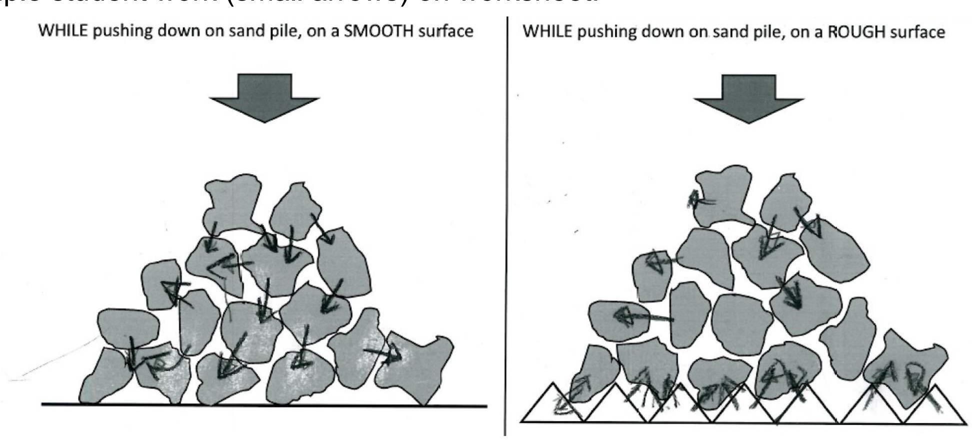
Teacher Background for modeling activity

Up to this point, we have only focused on large collections of sand grains — how sand acts in a pile, or how layers of sand and textiles behave. In this lesson, we want to direct students' attention to the individual grains of sand. If we focus on the scale of the sand grains, we can see how they push on each other, and how they might interact with the textile materials. This is likely a new experience for students! By zooming in close, we can see that sand grains are sharp and spiky (angular), NOT smooth balls, like marbles. That shape property accounts for how and why a pile of sand can support weight and hold stuff up. We can also look really closely at the layering materials-- some are very smooth, and some have tiny bumps. Putting the spikiness of the sand grains together with the surface of the layering materials, we can imagine that some of the sand grains get trapped in the tiny bumps of the layering materials. Then, the sand grains above get stopped from slipping off the pile because they get trapped between angles in the sand below them. This goes on and on, up the pile, and as a result, the sand grains can't move sideways, and they make a pile. In more technical language, we are working towards developing an understanding of how (bidirectional) friction acts at the particle scale.

This exercise also helps us understand how the properties of individual *particles*, and interaction between those particles (and in this case, other objects), affect the behavior of the sand pile (*aggregate)*. In more technical language, the study of "particle-aggregate behavior". This is a big concept, but this specific example can help students begin to think in terms of particles and their interactions. It may be helpful (for your own understanding, and to bring up to students!) to compare the sand situation to a pile of perfectly smooth balls, like marbles. Would a pile of marbles stand up? What if you put them in something really bumpy, like an egg carton?

We have found that some fourth graders can fill in the worksheet without trouble, and grasp the concept of the rough surface (layering materials) pushing back against the sand grains to keep the pile from completely flattening out. Others "get it" when their group members explain it with the arrows, and others are not quite ready for the concept. Even for those students who don't seem to be making all the connections, we still feel it is beneficial to get the exposure.

Example student work (small arrows) on worksheet:



This student seems to be reasoning that the bumps (represented as triangles) of the rough surface are pushing back against the sand grains and trapping them in the spaces between the triangles. This is why the pile on the rough surface does not spread out as far.

Lesson Sequence

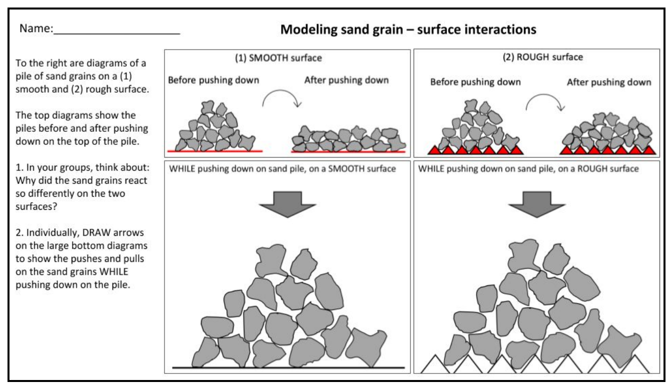
1. Modeling sand grain-surface interaction (25 min)

Introduce the modeling activity (10 minutes)

- Use the Lesson 5 Sand Grain Forces Modeling slides (p. 53-62, Resources) for the introduction to this modeling activity. The slides include:
  - Think-pair-share: What shape is a sand grain? What does a pile of sand grains look like?
  - Shows magnified pictures of grains
  - Demo Push & Pulls and how to draw them with arrows (can use "forces" if that language is already familiar to all students)
  - Pictures of the handout, to explain in more detail the top and bottom and what the instructions are

Students work on handouts in groups (10 minutes)

- Pass out handouts on sand grain - surface interactions (p. 64, Resources)
- Emphasize that students are NOT trying to figure out which surface is better--we already know from the top of the sheet that the rough surface results in a taller pile. The goal is to figure out WHY that is the case. (Otherwise, some students will determine which one "wins" (rough) and stop working at that point.)



- Give students 5-10 minutes to individually draw arrows showing pushes and pulls on their handouts, and to talk to their group members about it
- If there is time, give groups different layer materials (mesh, fabric, wax paper) to observe closely, using hand lenses if you have them. Which materials seem "smooth"? Which ones seem "rough"? Which might we want to use while building?

Whole class sharing (5 minutes)

- Structure a whole class discussion to share what they learned/discovered. You can pull a few students who had great handouts to share what they did and explain their reasoning.

2. Review & introduce the final design challenge (5 min)

Review the unit so far using final slides from the Unit Review and Design Challenge section of the Resources file (p. 65-70). Use the photograph to review how the basin models the MBTA green line extension construction site.

Tell students that today they will plan their solution to the geotech problem based on everything they have learned so far in this unit. Distribute or display the Final Design Brief (a version is also on p. 69 of the Resources document).

3. Plan solutions, discuss as a whole class, revise (20 min)

Plan solutions (8 min)

- If you are worried about strong personalities dominating the group planning time, allot about 5 minutes for students to sketch and/or write their design ideas individually.
- In design groups, have students share and record design ideas in their team engineering design notebook.
  - Design groups should use their engineering design notebooks to record plans for one or more designs that they will construct and test.
  - Each design plan should include both a diagram and a list of materials.
  - **The goal is to have a well enough established plan to start building immediately in the next lesson.**
  - If groups finish quickly and want to start building, instead encourage them to come up with a back-up plan or questions they would like to ask the class in the whole class discussion (e.g., "Do you think ____ will work?" "We are unsure about [some part of their plan]")

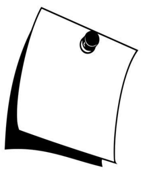
Share plans with other students (8 min)

- Options:
  - Whole-class share out from each team, with questions from others
  - Pair teams and have them share plans and get feedback from each other
  - Gallery walk--have teams leave their plans on their desks, then walk around with sticky notes to the other teams and give feedback (this is tricky to manage if it's new to students. In that case, might need more scaffolding than just sticky notes)
- Encourage students to think about what they can learn from explaining their own design and listening to other design plans because they will have a chance after the discussion to refine their plans.
  - One way to structure this is to have each group describe their plan, then ask for "?+Δ" (? = question, + = something good, Δ = a suggestion for improvement, a change) from the class.
  - Draw attention to some salient features of the plans. For instance:
    - Is everyone using stabilizing layers? Are different groups planning to use different materials or thicknesses? Did they explain why?
    - If all groups have similar plans, encourage the class to think about other plans together. What are the variables that can be changed? (material of the wall, angle of the wall, number of walls, size of wall(s), way materials are attached, materials of the layers, layer thickness)
    - If one plan really stands out for some reason (very different from the others, synthesizes knowledge from the inquiry days in a sophisticated way, the team describes an interesting process of designing their plan, the team has a unique plan for the actual building of their design), give

that team space to describe their reasoning and encourage other teams to see them as an example.

Revise plans (4 min)

- Have students return to their teams to note or make any changes to their plan that were inspired by the whole class discussion. Help students engage in argumentation with evidence to decide how to revise to their design plans. (Students may be tired of writing at this point. Simply circling areas is completely fine! We want to make sure the sharing is not just a procedural task, but truly impacts designs.)



Note Some students may feel like they're "copying" if they use an idea they heard from another group. If you have the sense that students are feeling this way, you can share that, in engineering, "copying is a compliment" and that it is acceptable and encouraged to be inspired by what others have done. Some teachers use "there is no private property here," throughout the year, to emphasize that everyone is working to deepen knowledge as a whole class.

Lesson 6: Full Design Challenge

Lesson 6 Overview

Activities

1. Build and test first iterations (design groups) (until each group has tested at least once, 15-20 min)
2. Break for whole class discussion (whole class) (10 min)
3. Continue to build and test final prototypes (design groups) (the rest of class, 25-30 min)

Objectives

- Students will collaboratively build and test prototypes of their design solutions.
- Students will discuss their prototypes and test results as a whole class.
- Students will consider insights from the whole class discussion to redesign their prototype.

NGSS Alignment

4.3-5-ETS1-3. Plan and carry out tests of one or more design features of a given model or prototype in which variables are controlled and failure points are considered to identify which features need to be improved. Apply the results of tests to redesign a model or prototype.

4.3-5-ETS1-5(MA). Evaluate relevant design features that must be considered in building a model or prototype of a solution to a given design problem.

SEPs: Constructing explanations & designing solutions, Engaging in argument from evidence, Obtaining, evaluating, and communicating information

Materials

For each group of students

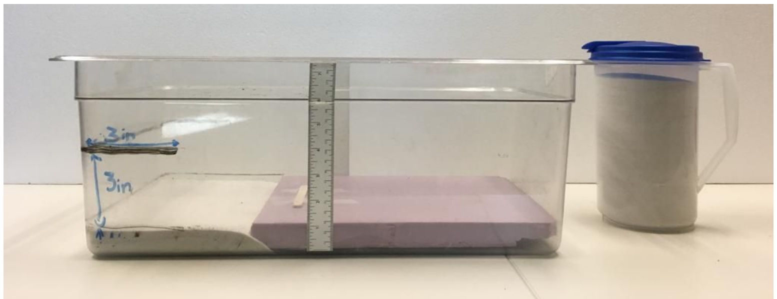
- Engineering design notebook
- Prepared construction bin
- Testing materials
  - 2-QT pitcher of sand
  - Brick
- Copy of Final Design Brief (p. 69, Resources)

For each group of students (cont'd)

- One prepared testing bin (foam + sand layer)
- Construction materials
  - Small post-it notes or slips of paper (roughly 1.5" x 2")
  - Toothpicks
  - Paper clips
  - 3 inches of tape
  - Squares of textile

Preparation

- Prepare the construction bins as outlined in Lesson 3 (**Preparation**).



- Determine how you will distribute materials to students. You can prepare material kits for each design group, set up a distribution center with the materials laid out, etc.; whatever works for your classroom.

Note about limited sand in the classroom

If you have limited sand, prepare each group's construction bin with a 1" base layer of sand, but do not provide them with a pitcher or brick. Instead, set up two testing stations. At each, place one brick and one 2-QT pitcher of sand. Students can plan and build their structures in their team's construction bin at their workspace. When they are ready, they can come to the testing stations to add sand, test their retaining wall with the weight of the brick, and shake to simulate train rumbling.

Lesson Sequence

1. Build and test first iterations (10-15 min)

Today students will be doing all of the building, testing, and iterating of this design challenge. Let them get to building as soon as possible!

Have students get into their groups and start building their plan from last class (Lesson 5).

- Some teams may choose to add all of their sand as they build; other teams may choose to add the rest of their sand when their retaining structure is completely constructed. (If groups are sharing testing sand, then they will have to add it all at the testing station.)
- Circulate throughout the room. Pay attention to:
    - Is everyone contributing? Is there enough work so that all hands are on deck?
    - How closely are students sticking to their plans? By no means are they required to, but it's interesting to see in what ways building something from a plan actually happens.
    - How many iterations do you notice? Are students making constant small changes to their structures? Are students creating a new plan as a group after a failed test?

- ○ Are students providing reasons to each other (and/or you) as to why they are making any changes?
- ○ Are students documenting their tests? Are they thinking about previous iterations while designing future ones?

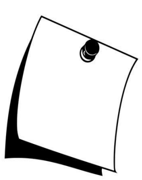
2. Whole class discussion of progress (10 min)

When you think the class is ready (every group has tested a design at least once), interrupt the building process for a short whole-class discussion. This may be difficult, as students will be very invested in their prototypes. Keep this discussion short and focused on one or two designs or features you'd like to highlight. Think back to the interesting discussion points from the whole-class share out during Lesson 3, after the midpoint design challenge. You might choose to highlight:

- A design that is surprisingly successful. Can the whole class figure out together why this design is so successful?
- A design that is surprisingly unsuccessful. Can the whole class help a team figure out why their retaining wall isn't holding back the sand?
- Similar or different features across the designs of the entire class. Examples:
  - Does everyone have a vertical wall? How well is this working?
  - Does everyone have different thickness of layers? Are they working equally well or do some thicknesses work better than others?
  - Something else?
- An inventive or unexpected use of a building material.
- An interesting method of testing the design. Examples:
  - Does a team pour sand behind their structure?
  - Does a team use their structure to push back a pile of sand?
  - Something else?
- Anything else that stands out or could help the whole class further refine their thinking about the mechanics of the design solutions, the building materials, or holding back earth materials in general.

3. Build and test final prototypes (25-30 min)

Have the class return to their design groups to continue building and testing. Encourage them to think about how elements of the whole class discussion can help them to improve their design.



Note Documentation at this point is very important. Students will need to accurately remember their design for the design memo activity during Lesson 7. Take pictures of their final designs or have students make a detailed, labeled sketch.

Clean up. Announce that next class students will summarize what they learned throughout this design challenge by creating "design memos." In the design memos they will create a labeled sketch of their design and identify a feature that worked well and a feature that could be improved. Then, on the last day of the unit, they will use these memos to share their designs with the class and make "rules of thumb" for retaining system designs.

Lesson 7: Design Challenge Reflection

Lesson 7 Overview

Activities

1. Whole class discussion about design memos and identifying features (whole class) (15 min)
2. Create Design Memos (35 min)
    - Plan individually: sketch design and identify one feature that worked well and one that could be improved (15 min)
    - Refine as a group: come up with a consensus version of the design memo (20 min)

Objectives

- Students will identify features of their design that worked well and could be improved.
- Students will represent their design in a labeled sketch, with intentions of sharing the sketch with a broader audience.
- Students will collaboratively decide how to best represent their design and which feature was most critical for success and most in need of improvement.

NGSS Alignment

4.3-5-ETS1-5(MA). Evaluate relevant design features that must be considered in building a model or prototype of a solution to a given design problem.

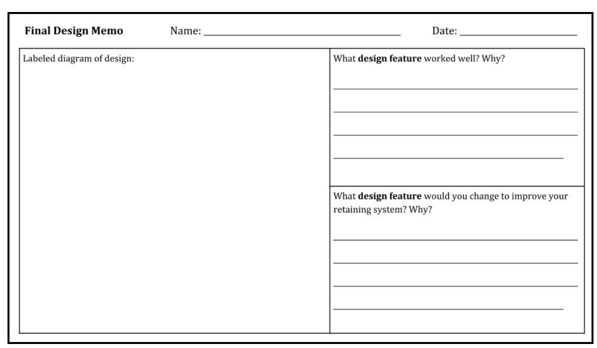
3-5-ETS1-2 Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

SEPs: Constructing explanations & designing solutions, Engaging in argument from evidence, Obtaining, evaluating, and communicating information

Materials

For each group of students

- Design memo template (p. 72 in Resources)
    - One for each group member + a final version for each group
- Writing utensils
- Engineering design notebook
- Big sticky notes, two per group

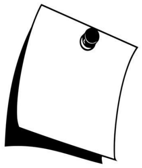


Final Design Memo Name: ____________ Date: ____________

Labeled diagram of design:	What **design feature** worked well? Why?
	What **design feature** would you change to improve your retaining system? Why?

Preparation

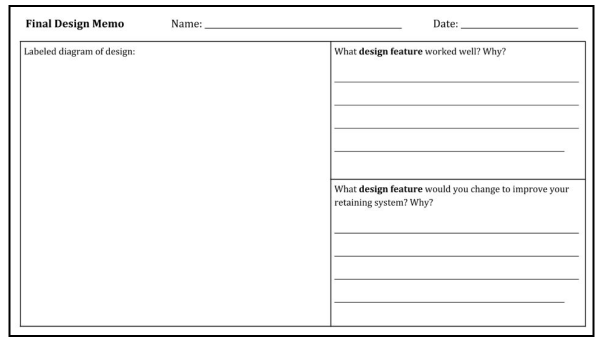
- Print enough design memo templates (p. 72 in Resources) for each individual student, plus a final version for each student group.



Note You will want to collect each group’s final design memo so they can be copied for Lesson 8. If students put their features on sticky notes, hang onto those for Lesson 8.

Lesson Sequence

1. Whole class discussion: sharing designs (15 min)



Final Design Memo Name: ______________ Date: ______________

Labeled diagram of design:

What **design feature** worked well? Why?

What **design feature** would you change to improve your retaining system? Why?

   - Gather the class and share the plan for the day. First, the class will discuss the plan to share their design solutions in the last lesson. Then, individually and in groups, they will sketch their design, think about features that worked well and could be improved, and create the design memos for the design sharing (Lesson 8).
   - Show students the design memo template (p. 72, Resources). Talk about how this template will ask them to highlight *features* of their designs. Every design has many parts; each of these is a feature. Some features work very well and help the design accomplish a task. Other features may present challenges.
   - If you plan on inviting visitors on Day 8 to look at student designs (perhaps as a “Design Expo”), have students think about and list as a class some questions visitors to the expo might ask about their designs. In groups, they can then think of answers for their group to these questions.

2. Design memo work (35 min)

Individual work (10-15)
Give each individual student time to fill out their own copy of the design memo template. Encourage them to focus on the sketch, identifying one feature that worked well, and one that could be improved (can be simply circled in different colors if writing is a chore). Inform them that after they’ve done their own, they will work with their design group to create a final version. This will require them to defend their choices and consolidate the different ways they represented their design through the sketch.

Group work (20-25)
Have each small group do a “round robin” sharing of their individual design memos. Have the students create a final version of the design memo as a team. Encourage them to look back on their engineering design notebook to describe their design, test results, and gather evidence to support their recommendations. At this stage, students may choose to highlight more than one feature that worked well or could be improved. If time allows, have students write their feature that worked well and feature for improvement on large sticky notes (one sticky note for each feature) to prepare for the activity during Lesson 8.

Lesson 8: Design Feature Review

Lesson 8 Overview

Activities

1. Group-to-group sharing of design memos. Students compare and contrast their designs, focusing on the features the other team identified and the features they identified. (20 min)
2. Students do a final revision of their design memos based on their interaction with the other group(s). (10 min)
3. Whole class activity to organize features that worked well and features that could be improved. (20 min)

Objectives

- Students will present their design memos to another group.
- Students will compare and contrast their design sketches and features that worked well and could be improved with another group.
- Students will synthesize the experiences of the entire class into categorizations of things that did and did not work well in their design of the retaining system.

NGSS Alignment

3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

4.3-5-ETS1-5(MA). Evaluate relevant design features that must be considered in building a model or prototype of a solution to a given design problem.

3.3-5-ETS1-4(MA). Gather information using various informational resources on possible solutions to a design problem. Present different representations of a design solution.

SEPs: Constructing explanations & designing solutions, Engaging in argument from evidence, Obtaining, evaluating, and communicating information

Materials

For each group of students

- Engineering design notebook
- Two copies of their design memo (from Lesson 7)
- Big sticky notes

Preparation

- Make at least one copy of each group's final design memo from the end of Lesson 7.

Lesson Sequence

Explain to students the flow for the day: first, they will look at another group's design memo and compare and contrast it with their own, then they will have a chance to revise their design memo before the whole class activity of organizing the features that worked well and that could be improved from every group. **The overall goal of the day is to identify common themes among design features that worked well and design features that did not work well.**

1. Group-to-group sharing (20 min)

Pair up student groups. Have each group take turns briefly describing their sketch and the features they identified. Then give the groups time to spend with their own design memo and a copy of the other group's design memo, looking for similarities and differences between the designs and identified features. If it seems like it would be beneficial for your students, have them record on paper the similarities and differences they notice.

2. Final revisions (10 min)

If desired, give students time to revise their design memo in their design groups. Provide them with big sticky notes; have them describe their feature that worked well on one sticky note and their feature that could be improved on a different sticky note.

3. Whole class organization activity (20 min)

Have students put their big sticky notes on the board, briefly explaining them to the class. It may make the most sense to do features that worked well first, then also look at features that could be improved. As a group, help students identify clusters of features that are similar. Rearrange the sticky notes and use the board to annotate what students are noticing and any names for categories that emerge. The end goal of this activity is a set of categories that capture what the whole class learned about what does and does not work in the design of a retaining system. These can be translated into "rules of thumb" or something like a list of recommendations for the MBTA working on the Green Line Extension project.

This activity draws from the math education technique of Bansho (Japanese for "board writing." For more information on this technique, refer to this piece about communication in mathematics classrooms). This technique requires simultaneous comparison of multiple solutions and has the potential for students to construct new ideas and deepen their understanding.

Resources

Materials

This materials list assumes a classroom of ~24 students, with 6 groups of 4 students each. The total cost to purchase everything for the unit is about $300.00. By using materials you may have on hand, or coordinating with other teachers to share items that come in large quantities (like sand, bins, and 11x17" transparency sheets), the cost can be greatly reduced.

For the fabric materials, you can try finding alternatives at thrift stores or cutting up old t-shirts. For some of the earth materials, like soil, gravel, and bricks, you can try to find local or "used" alternatives for cheap or free. It may be helpful for storage and organization of sand to use 5 gallon buckets from Home Depot or similar.

The links included in the spreadsheet below go to common sources, like Amazon or Home Depot. The prices listed are based off of the links and may fluctuate over time. It is okay to purchase these materials from anywhere that you can find, the specifics are not critical.

Item	Amount	amt / unit sold	units to order / class	Cost per item	Total per Class
Test bin setup					
Non-toxic play sand (Sandtastik)	50 lbs / class	25 lbs	2	$16.95	$33.90
Clear basin, 12 x 20 x 8"	1 / team	1	6	$16.62	$99.72
Pouring containers, 2 QT	1 / team	6	1	$23.99	$23.99
Concrete brick	1 / test station	1	2	$0.55	$1.10
Pink foam, 1" thick, cut into 12" x 10"	1 / team	2' square	2	$5.98	$11.96
Craft sticks or skewers, 6"	4 / team	100	1	$4.41	$4.41
Ruler tape	2' / team	41	1	$8.99	$8.99
Lesson 2: Piles Inquiry					
Cardboard circle (5-7" diameter)	1 / group	12	1	$6.99	$6.99
Dixie cups	3 / group	100	1	$6.25	$6.25
Soil or potting mix	~ 2-QT /station	8 QT	1	$4.89	$4.89
Angular gravel	~ 2-QT /station	0.5 cu ft	1	$14.81	$14.81
Smooth aquarium pebbles	5 lb / station	5 lb	2	$3.98	$7.96

Wall building materials (Lesson 3 + Design Task)					
Small post-it notes (1.375" x 1.825")	50 / team	1600	1	$9.99	$9.99
Toothpicks	20 / team	2500	1	$3.06	$3.06
Small paper clips	20 / team	1000	1	$7.19	$7.19
Masking tape	10" / team	55 yards	1	$8.25	$8.25
Textile + tube materials (Lesson 4 + Design task)					
Transparency sheets (11 x 17"), 1 / grp	1 / group (6)	25	1	$26.99	$26.99
Clear packing tape	2 ft / group	76 yards	1	$5.97	$5.97
Mosquito netting (cut into 40 3.75" squares)	4 ft x 1 ft * 2	4 ft x 15 ft	1	$9.80	$9.80
Cotton jersey (cut into 40 3.75" squares)	1/3 yard x 5 ft wide + extra	1 yard	1	$8.93	$8.93
Wax paper (cut into 40 3.75" squares)	5 ft x 1 ft	75 ft x 1 ft	1	$1.59	$1.59
Design Feature Review (Lesson 8)					
Big sticky notes	2 / group	270	1	$13.99	$13.99
					$323.98

Eleanor the Geotechnical Engineer

Eleanor is a geotechnical engineer. A geotechnical engineer is a special kind of civil engineer who uses their knowledge of soil and earth materials to make sure landscapes are safe to build on. Eleanor works at the Massachusetts Bay Transportation Authority, or MBTA, for short. The MBTA helps people travel from place to place in the Boston area on trains, subways, buses, and even ferries. In Eleanor's job, she changes landscapes so that trains can safely travel through them. Eleanor loves working with trains because she rides them every day to get to and from work.

Eleanor is currently working with a team on a special project for the MBTA. Their project is to help more people get where they need to go by extending the Green Line of the train system. Eleanor needs to make train tracks to new places so that people can get to more places on the train. Eleanor has been designing the new train tracks easily until today. She is having a bit of trouble thinking about how to make one section of the tracks. This section needs to go next to the road, but be placed *below* the level of the road. This means some earth material, like soil and rocks, needs to be pushed out of the way so the tracks can be on flat ground.

Notice how the picture on the left shows a flat roadway with cars and trees, and the other photo shows a train on tracks *below* the road.

Eleanor wonders if the soil and rocks could be pushed into a big pile to make space for her tracks, but there is one big problem with that plan. The soil and rocks might start to tumble down the sides of the pile. A landslide like that could be dangerous for nearby people, and if there were soil, rocks, and other earth material on the train tracks, then the train would not be able to get through.

Eleanor imagines how awful it would be if earth materials started to slide onto the tracks. Then Eleanor remembers coming across the same problem long ago when she used to build sandcastles. She would fill up her blue bucket with sand, turn it upside down, and slowly remove the bucket. She hoped for a beautiful sandcastle, but every time she removed the bucket, the sand would spread out into a pile. Eleanor would try to push the sand back into the shape of the bucket, but no matter how hard she tried, the sand always slid down into the same pile.

Keeping earth materials in a particular place is a tough engineering problem! What do you think Eleanor could design to hold back the soil, rocks, and sand so that the new Green Line extension train tracks can be built?

Retaining Walk Observation Sheet

Location of wall (street address?)	How tall is the wall? (feet)	What is the wall made of?	Other observations about the wall? (Cracks, holes, tipping, terraces, special purpose)	Sketch of the wall

Final Design Brief

Goal: Design, build, test, and iterate on a **retaining system** that keeps sand away from the model train tracks, allows the sand to support the weight of a model building, and stays up when the train goes by.

Criteria:

Your retaining system MUST:

- Keep all sand off of the pink foam and model train tracks.
- Withstand "train rumbling" (shaking the basin).
- Keep the sand stable enough that it can hold up a model "building" (brick).
    - The building MUST be kept level, so it does not tilt.
    - The building is located 4 inches above the base of the basin (3 inches above the sand) and 3 inches away from the short side.

Constraints:

- You may build your retaining system only with:
    - Small slips of paper (1.5" x 2")
    - Small paper clips
    - Toothpicks
    - 3 inches of masking tape
    - **Squares of textile material (fabric, mesh, wax paper)**
- Textile materials cannot be on the outside of the sand pile.
- You only have 1 class period to build & test your system.

Lesson 1

Unit Launch Storybook

In this project, we will be solving an engineering problem for the MBTA.

The MBTA (or the T) runs the buses, trains, and ferries in the Boston area.

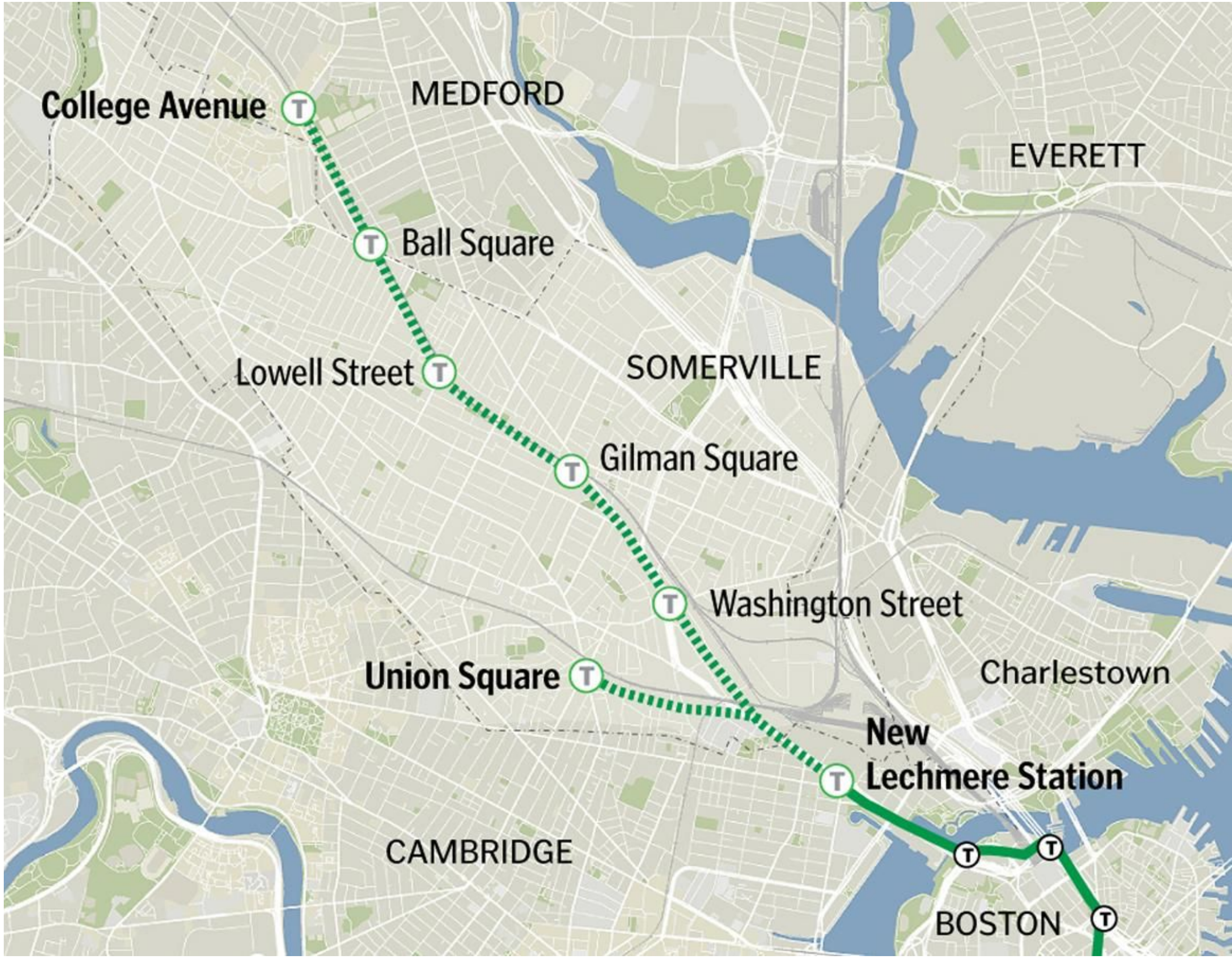
The routes are shown on this map.

The MBTA has many trains, buses, and ferries...

...including this Green Line trolley.

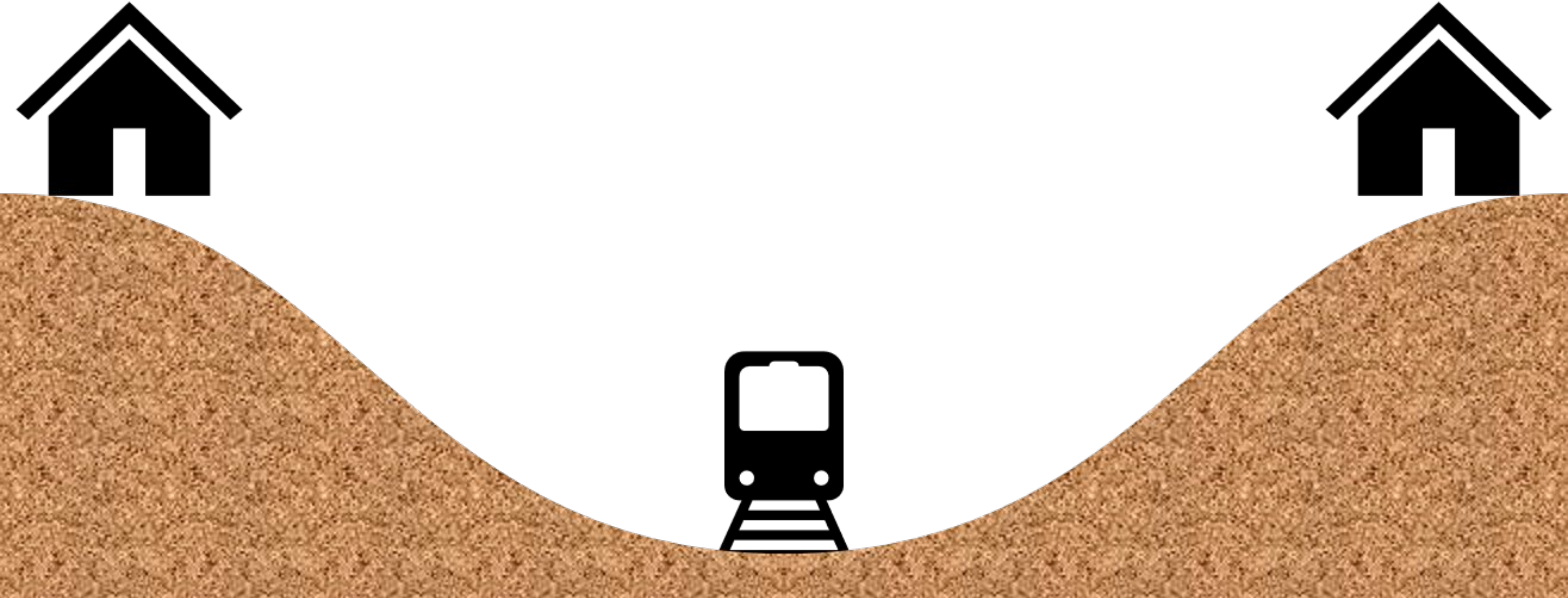
The trolleys run on the Green Line (mostly above ground).

The MBTA is currently extending the green line to new areas beyond Boston.

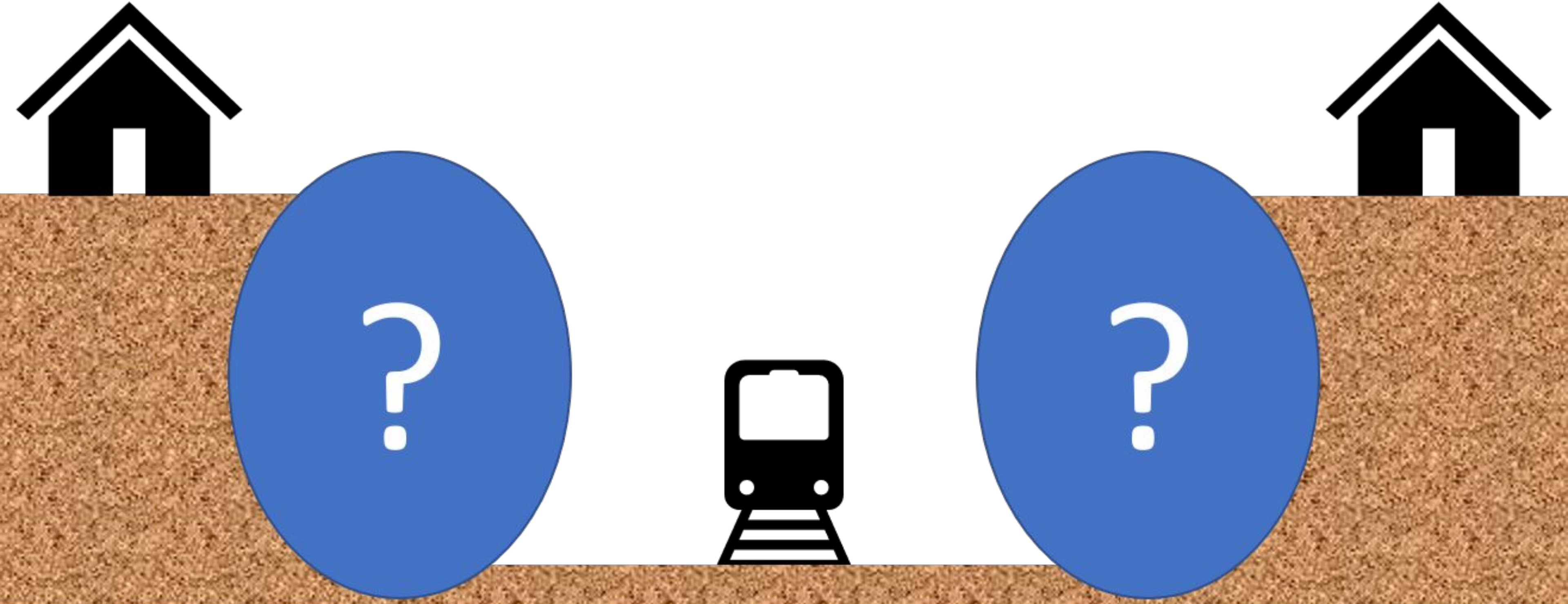


These areas are full of roads, houses, and stores. The new train tracks will need to go below these buildings.

If we try to just scoop out the soil, sand, and rocks, the houses will be unsupported and there will not be much room for the tracks.



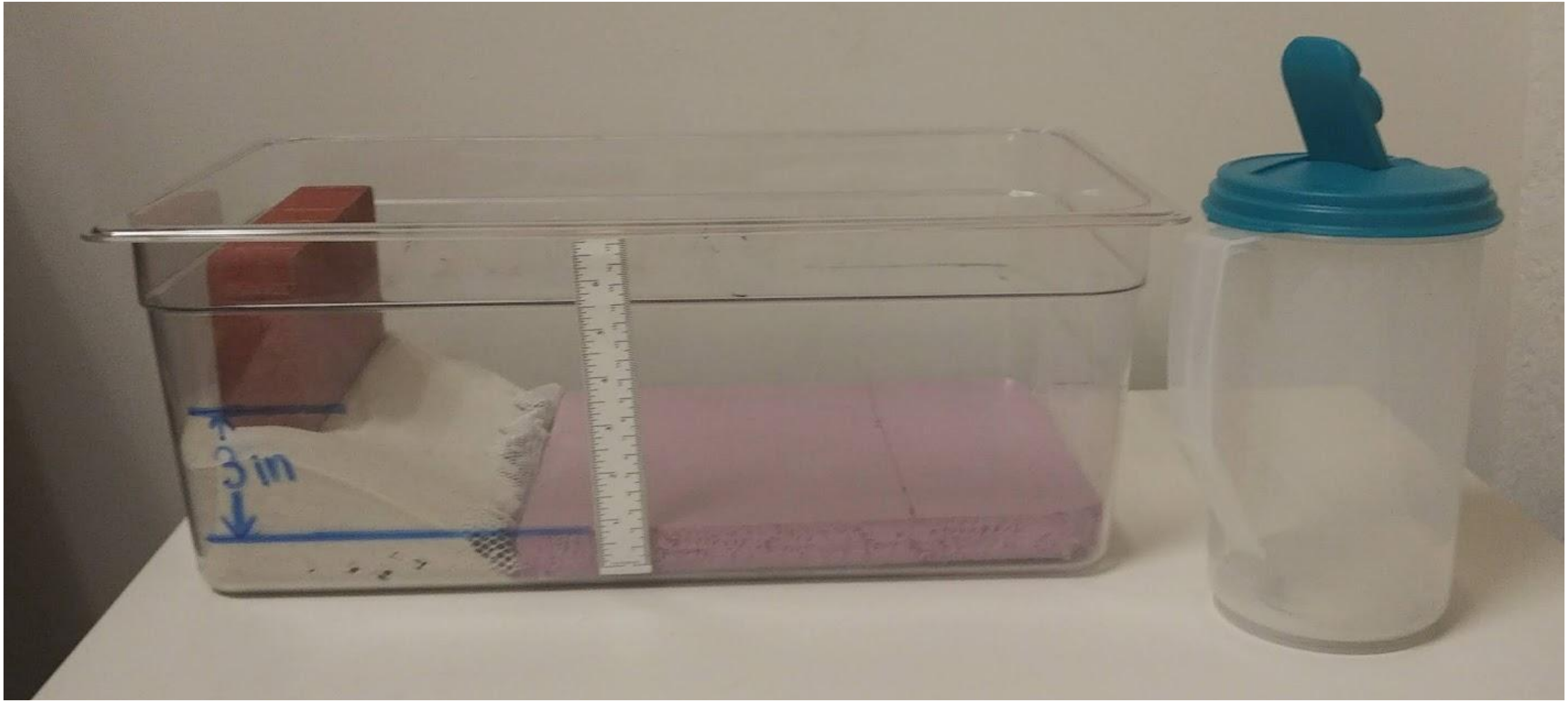
What can we build to keep earth materials off the new train tracks while still supporting the houses?



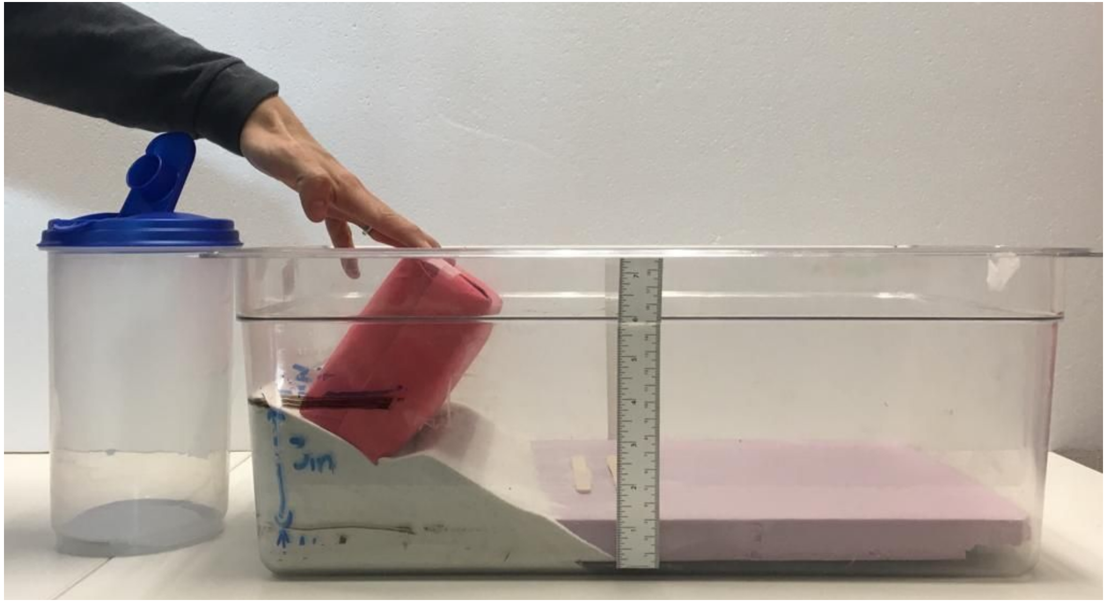
We will explore:

How can we keep earth materials off new train tracks?

Your task for this whole project is to create a scale model solution in a bin. Your group will design a structure that can keep sand off the train tracks and hold up a weight 3 inches off the ground.



Today, we'll see what happens when we try to keep the sand off the tracks and keep the "house" level without any extra materials, so we can better understand the problem the engineers face.



Lesson 1

Eleanor the Geotechnical Engineer

Eleanor the Geotechnical Engineer

Eleanor is a geotechnical engineer. A geotechnical engineer is a special kind of civil engineer who uses their knowledge of soil and earth materials to make sure landscapes are safe to build on. Eleanor works at the Massachusetts Bay Transportation Authority, or MBTA, for short. The MBTA helps people travel from place to place in the Boston area on trains, subways, buses, and even ferries. In Eleanor's job, she changes landscapes so that trains can safely travel through them. Eleanor loves working with trains because she rides them every day to get to and from work.

Eleanor is currently working with a team on a special project for the MBTA. Their project is to help more people get where they need to go by extending the Green Line of the train system. Eleanor needs to make train tracks to new places so that people can get to more places on the train. Eleanor has been designing the new train tracks easily until today. She is having a bit of trouble thinking about how to make one section of the tracks. This section needs to go next to the road, but be placed *below* the level of the road. This means some earth material, like soil and rocks, needs to be pushed out of the way so the tracks can be on flat ground.

Notice how the picture on the left shows a flat roadway with cars and trees, and the other photo shows a train on tracks *below* the road.

Eleanor wonders if the soil and rocks could be pushed into a big pile to make space for her tracks, but there is one big problem with that plan. The soil and rocks might start to tumble down the sides of the pile. A landslide like that could be dangerous for nearby people, and if there were soil, rocks, and other earth material on the train tracks, then the train would not be able to get through.

Eleanor imagines how awful it would be if earth materials started to slide onto the tracks. Then Eleanor remembers coming across the same problem long ago when she used to build sandcastles. She would fill up her blue bucket with sand, turn it upside down, and slowly remove the bucket. She hoped for a beautiful sandcastle, but every time she removed the bucket, the sand would spread out into a pile. Eleanor would try to push the sand back into the shape of the bucket, but no matter how hard she tried, the sand always slid down into the same pile.

Keeping earth materials in a particular place is a tough engineering problem!

What do you think Eleanor could design to hold back the soil, rocks, and sand so that the new Green Line extension train tracks can be built?

Lesson 1

Professional Profiles

What does Marybeth do at the MBTA?

I am a Climate Resiliency Specialist in the Environmental Department. “Climate resiliency” means the T is able to handle the changes in weather caused by Earth’s changing climate over a long time. One big weather change is more storms that are bigger than usual. When big storms happen, the subway tunnels can flood and cause problems for the T. I use science and engineering to prepare the T to survive in big storms.

What does Alex do at the MBTA?

I work in the safety department. I investigate accidents on the T. Some accidents that happen are crashes or trains coming off the tracks. People tell me about an accident, and I use my engineering knowledge to investigate their report.

What does Kathryn do at the MBTA?

I am a project manager in the accessibility department. The accessibility department makes sure that passengers with disabilities have equal access to the T. Issues for wheelchair users include elevator access and ramps from the platform onto the train car. My team uses engineering to design solutions to make the T more accessible.

What does Michael do at the MBTA?

I am a machinist for the MBTA. Vehicles on the T sometimes break down and need repairs. I fix utility vehicles, mostly the kind used to clear snow in the winter. These vehicles do not carry passengers, but they are important to keep the T running all year. During the big storm in 2015, I designed a special snow blower for clearing snow off the tracks more efficiently.

Lesson 1

Who Can Help? Matching Game

Station Flooding

What does Marybeth do at the MBTA?

I am a Climate Resiliency Specialist in the Environmental Department. "Climate resiliency" means the T is able to handle the changes in weather caused by Earth's changing climate over a long time. One big weather change is more storms that are bigger than usual. When big storms happen, the subway tunnels can flood and cause problems for the T. I use science and engineering to prepare the T to survive in big storms.

Train Derailment

What does Alex do at the MBTA?

I work in the safety department. I investigate accidents on the T. Some accidents that happen are crashes or trains coming off the tracks. People tell me about an accident, and I use my engineering knowledge to investigate their report.

Train Station Announcements

What does Kathryn do at the MBTA?

I am a project manager in the accessibility department. The accessibility department makes sure that passengers with disabilities have equal access to the T. Issues for wheelchair users include elevator access and ramps from the platform onto the train car. My team uses engineering to design solutions to make the T more accessible.

Bus Accident

What does Alex do at the MBTA?

I work in the safety department. I investigate accidents on the T. Some accidents that happen are crashes or trains coming off the tracks. People tell me about an accident, and I use my engineering knowledge to investigate their report.

Tracks Flooding

What does Marybeth do at the MBTA?

I am a Climate Resiliency Specialist in the Environmental Department. “Climate resiliency” means the T is able to handle the changes in weather caused by Earth’s changing climate over a long time. One big weather change is more storms that are bigger than usual. When big storms happen, the subway tunnels can flood and cause problems for the T. I use science and engineering to prepare the T to survive in big storms.

Broken Down Train Car

What does Michael do at the MBTA?

I am a machinist for the MBTA. Vehicles on the T sometimes break down and need repairs. I fix utility vehicles, mostly the kind used to clear snow in the winter. These vehicles do not carry passengers, but they are important to keep the T running all year. During the big storm in 2015, I designed a special snow blower for clearing snow off the tracks more efficiently.

Wheelchair Ramps

What does Kathryn do at the MBTA?

I am a project manager in the accessibility department. The accessibility department makes sure that passengers with disabilities have equal access to the T. Issues for wheelchair users include elevator access and ramps from the platform onto the train car. My team uses engineering to design solutions to make the T more accessible.

Snow on the Tracks

What does Michael do at the MBTA?

I am a machinist for the MBTA. Vehicles on the T sometimes break down and need repairs. I fix utility vehicles, mostly the kind used to clear snow in the winter. These vehicles do not carry passengers, but they are important to keep the T running all year. During the big storm in 2015, I designed a special snow blower for clearing snow off the tracks more efficiently.

Lesson 3

Intro to Retaining Walls

How do geotechnical engineers keep back earth materials?


11 Sheridan St
Boston, Massachusetts
Google, Inc.
Street View - Jun 2016
Have you seen these in your neighborhood?
Day St
Paul Gore St
Google
Sheridan

What are **retaining walls**?

“Retain” = to keep back

Retaining walls are walls that “keep back” earth material (soil, dirt, sand, rocks)

What would happen if the rock wall in this picture wasn’t there? Where would all that soil go?

Think like a geotech engineer:

What materials are retaining walls made of?

When would you use which materials?

When would you create bigger or smaller retaining walls?

When would you create one single wall? When would you create a series of smaller walls (like terraces or large steps)?

What might cause retaining walls to fail?

Lesson 3

Mid-Unit Design Brief

Mid-Unit Design Brief: MBTA sand retaining system

Goal: Design, build, test, and iterate on a **retaining system** that keeps sand away from the model train tracks, allows the sand to support the weight of a model building that stays up when the train goes by.

Criteria (must have or do):

Your retaining system MUST:

- Keep all sand off of the pink foam and model train tracks
- Withstand “train rumbling” (shaking the basin)
- Keep the sand stable enough that it can hold up a model “building” at the marked location
    - The building MUST stay level, should not tilt
    - The building is located 4” above the base of the basin (3” above the sand) and 3” away from the short side

Constraints (limitations):

- You may build your retaining system with:
    - Small slips of paper (1.5” x 2”)
    - Small paper clips
    - Toothpicks
    - 3 inches of masking tape
- You only have 25 minutes to build your structure

Lesson 3 Extension

Retaining Wall Observation Sheet

Location of wall (street address?)	How tall is the wall? (feet)	What is the wall made of?	Other observations? (Cracks, holes, tipping, terraces, special purpose)	Sketch of the wall

Lesson 5

Sand Grain Forces Modeling

Modeling sand grain - surface interactions

Think-pair-share

What shape is a sand grain?

What does a pile of sand grains look like?

Let’s zoom in on this pile of sand...

Is this what you thought sand looked like magnified?
How might the shape of the sand grains matter for this challenge?

Let’s think about each sand grain!

Today, instead of just thinking about piles of sand, we’re going to think about EACH tiny sand grain, and how sand grains next to each other interact.

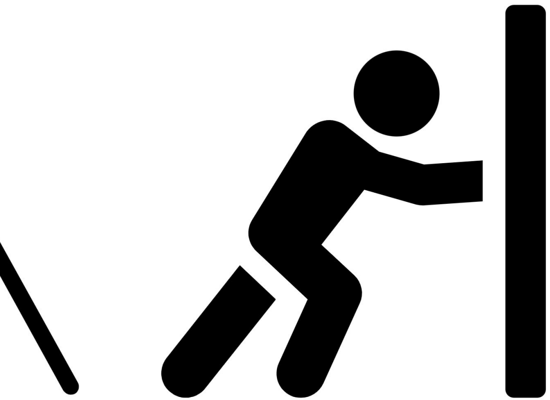
Because we can’t see sand grains easily, we’ll work with pictures of sand grains and “model” what we think is happening, if we could zoom in.

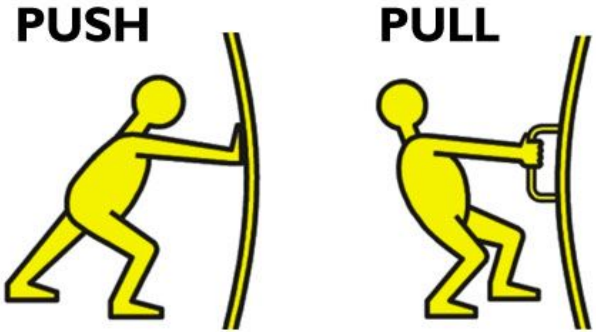
From the picture of magnified sand grains, we can imagine they look something like this:

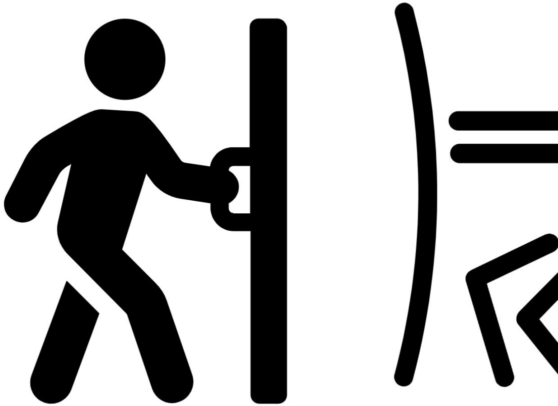
What is pushing and pulling on what?

When scientists and engineerings want to think about and “model” pushes and pulls, they often use arrows. The direction of the arrow shows which way the push or pull happens.

Which way would we draw an arrow to show how the person affects the door?







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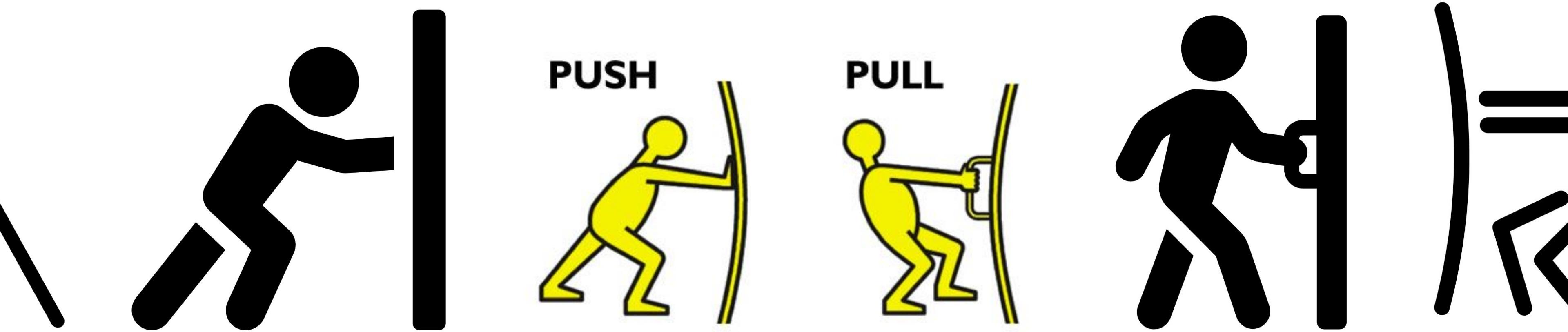
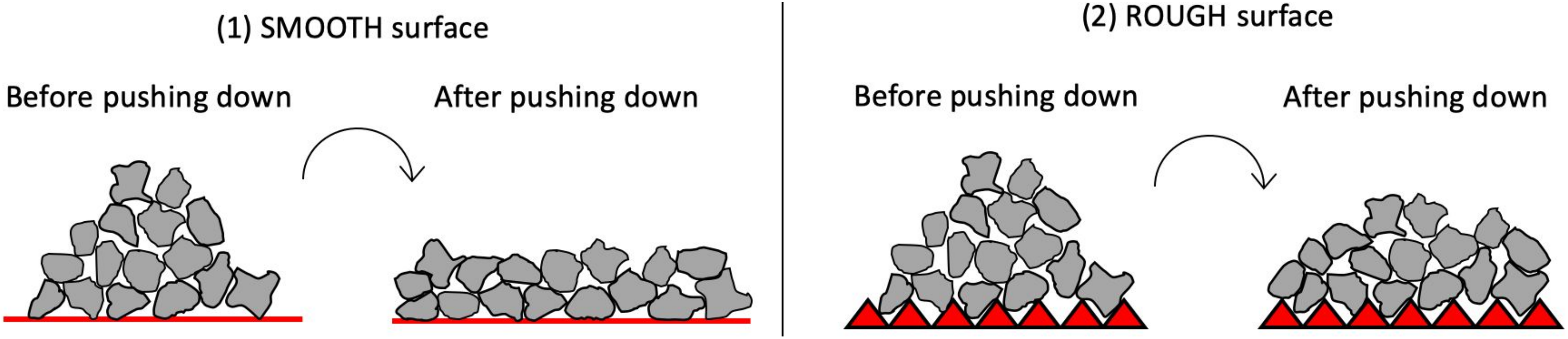


We want to find out: Why does “roughness” matter?

On the worksheet, we’re going to think about both smooth and rough surfaces:



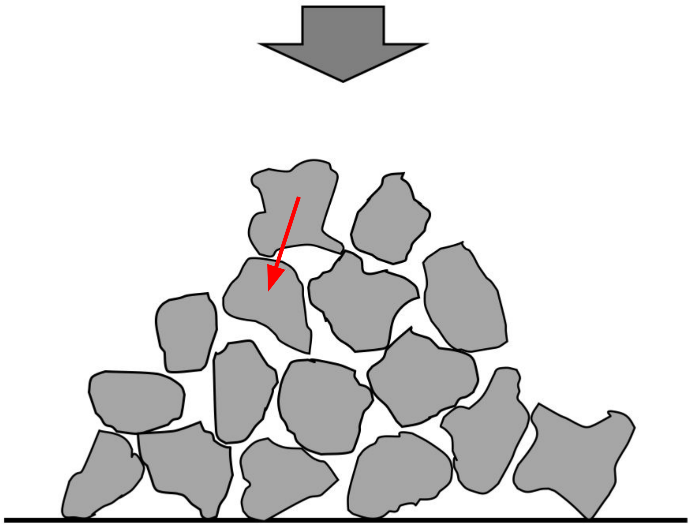
Which of the textile materials we used in layering could we consider smooth?

Which might we consider rough?

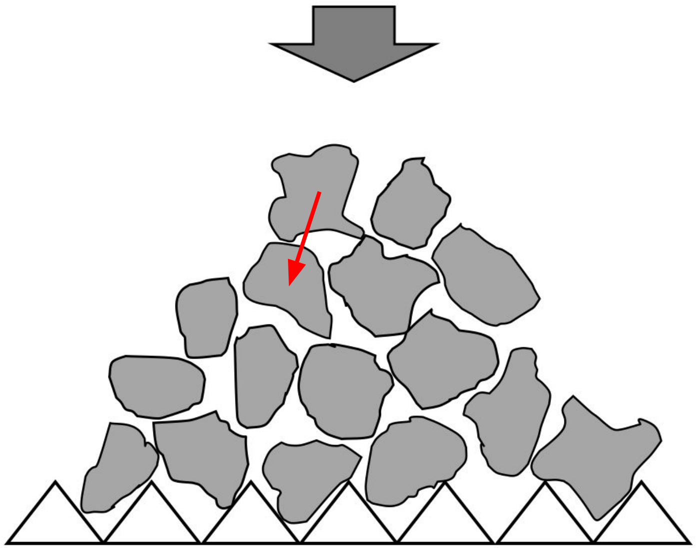
Why do the two piles behave differently?

On your worksheet, DRAW arrows to show the pushes & pulls on the sand grains that cause each pile to change shape. The red arrow might be your first one.

WHILE pushing down on sand pile, on a SMOOTH surface



WHILE pushing down on sand pile, on a ROUGH surface



Lesson 5

Modeling Sand grain-surface interactions

Name:______________________

Modeling sand grain – surface interactions

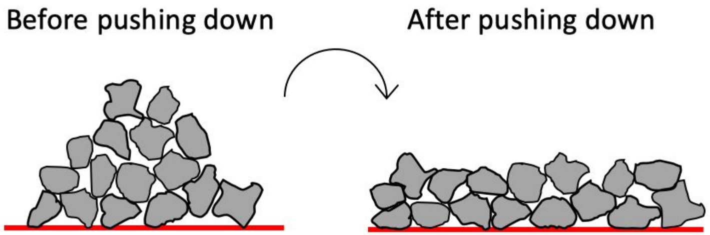
To the right are diagrams of a pile of sand grains on a (1) smooth and (2) rough surface.

The top diagrams show the piles before and after pushing down on the top of the pile.

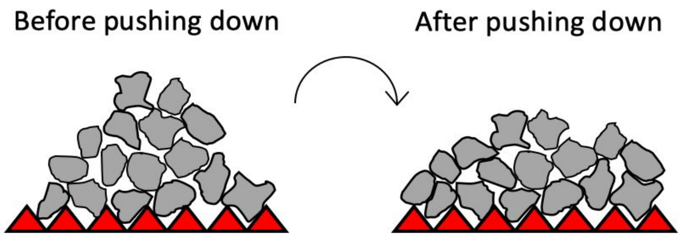
1. In your groups, think about: Why did the sand grains react so differently on the two surfaces?

2. Individually, DRAW arrows on the large bottom diagrams to show the pushes and pulls on the sand grains WHILE pushing down on the pile.

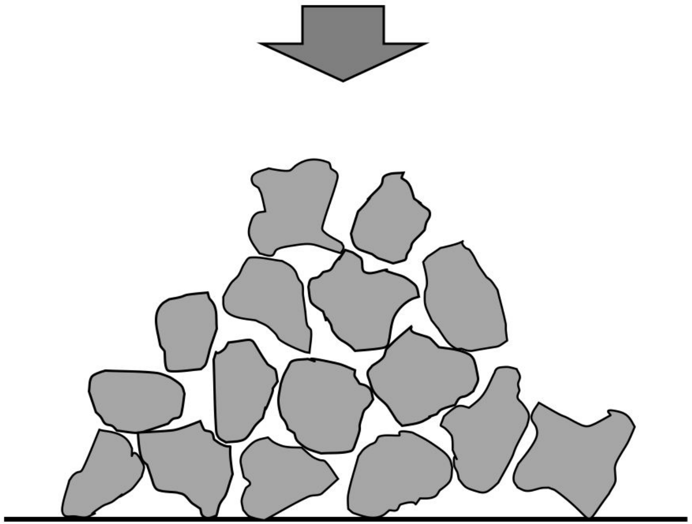
(1) SMOOTH surface



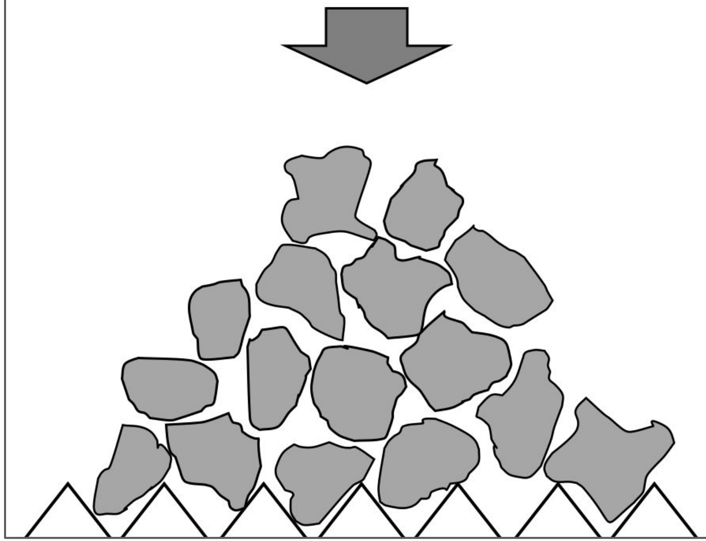
(2) ROUGH surface



WHILE pushing down on sand pile, on a SMOOTH surface



WHILE pushing down on sand pile, on a ROUGH surface

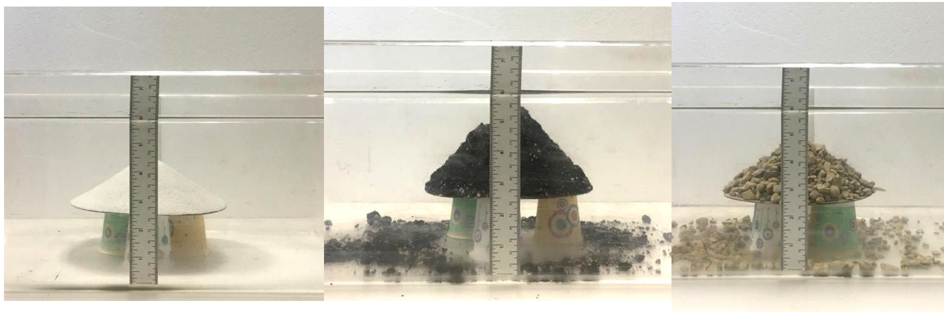


Lesson 5

Unit Review and Design Challenge

The final challenge!
(next time!)

Lesson 1: Learned about geotechnical engineering, got a feel for the problem



Lesson 2: Explored how earth materials make different slopes

Lesson 3: Learned about, built, and tested retaining walls

Lesson 4: Learned about and explored stabilization using textile layers

This is a picture from the actual green line extension project. The tracks already there are commuter rail tracks (big purple locomotives), the green line tracks will go next to them where the sloped dirt is.

What can we build below and near the houses to support them?

Today: plan!
Next class: build & test!

Final Design Brief: MBTA sand retaining system

Goal: Design, build, test, and iterate on a **retaining system** that keeps sand away from the model train tracks, allows the sand to support the weight of a model building that stays up when the train goes by.

Criteria (must have or do):

Your retaining system MUST:

- Keep all sand off of the pink foam and model train tracks
- Withstand "train rumbling" (shaking the basin)
- Keep the sand stable enough that it can hold up a model "building" at the marked location
  - The building MUST stay level, should not tilt
  - The building is located 4" above the base of the basin (3" above the sand) and 3" away from the short side

Constraints (limitations):

- You may build your retaining system with:
  - Small slips of paper (1.5" x 2")
  - Small paper clips
  - Toothpicks
  - 3 inches of masking tape
  - Squares of textile material (fabric, coffee filter, mesh)
- Textile materials cannot be on the outside of the sand pile
- You only have 1 class period to build your structure

Rest of today: Planning!

- 10 minutes: Sketch at least one design in your groups
  - Plans must be detailed enough for other students (not in your group) to figure out what you plan to make
- 15 minutes: Share plans between groups and get feedback
- 10 minutes: Review feedback and revise plans

Lesson 7

Design Memo

Final Design Memo Name: ______________________________ Date: ____________________

Labeled diagram of design:	What **design feature** worked well? Why? ______________________________ ______________________________ ______________________________ ______________________________
	What **design feature** would you change to improve your retaining system? Why? ______________________________ ______________________________ ______________________________ ______________________________