There and Back Again

Energy and Motion in the Journey to the Sanford Underground Research Facility

Lesson #	Lesson Title	Suggested Time
1	Journey to SURF Create and Diagram	60 minutes
2	Classifying Objects Make Measurements and Use Data	40 minutes
3	A Puzzle to Solve Build a Scale Model	60 minutes
4	A Soft Landing Gather Evidence	60 minutes
5	Engineering Design Challenge Design, Test, and Refine a Model	60 minutes

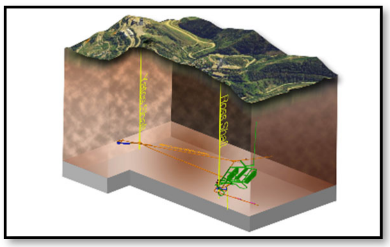
There and Back Again- 3-5 (Physical Science)
Phenomenon: Students are introduced to the cutting-edge science happening at the Sanford Underground Research Facility, located nearly one mile underground in Lead, South Dakota. They ask, *"How can people be safely transported there and back again?"* Students ask questions and gather evidence as they make sense of the energy changes required to lift and lower a heavy cage vertically a distance of nearly one mile.

Design Problem: Students will measure the Yates cage, construct a scale replica, and delve into the principles of energy, motion, and energy transfer. They will then design a system utilizing a motor to raise and lower their model cages.

There and Back Again

Storyline

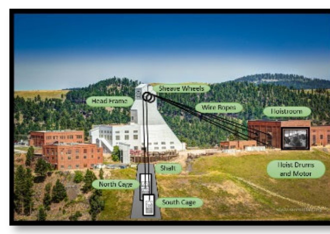
In this unit, students investigate energy transfer with a special emphasis on mathematical measurement and data. The unit begins with an engaging virtual journey to the Sanford Underground Research Facility in South Dakota, where hundreds of scientists are currently investigating dark matter, neutrinos, and other cosmic mysteries in a laboratory located nearly one mile below the earth's surface.



How can scientists be safely transported "*There and Back Again*" to a lab that rests beneath 4850 feet of solid rock? Students will ask questions and then tackle this engineering problem as they apply their scientific knowledge to design a model hoist system. Students use mechanical and electrical energy to lift and lower their model Yates cage as they explore the connections between the energy of an object and its speed.

The unit begins as students imagine themselves descending a dark shaft to the 4850 ft. level of the Sanford Lab, deep underground. Students gain a more accurate perspective of the journey to the underground lab by drawing a floor diagram of the "real-sized" Yates cage, given only a centimeter unit cube and the cage dimensions. Students create their own measuring device, using appropriate tools strategically. **(MP5)**

In the second lesson, students use pocket profile cards to meet some of the scientists, engineers and infrastructure support team members at the Sanford Underground Lab. Using their real-life cage floor diagrams, students must reason abstractly and quantitatively **(MP2)** to estimate and defend a value for the human capacity of the Yates Cage after calculating area and volume of the Yates cage.



In Lesson 3, there's a puzzle to solve! Students must use the cage dimensions to construct an accurate, scale model **(MP4)** of the Yates given a size constraint. **(Math Standards: 3MD8, 4MD3, 5MD5b)**

In Lesson 4, students use evidence from their investigations to construct an explanation relating the speed of the Yates cage to its energy. **(4-PS3-1)** Students will ask questions and predict outcomes about the results of releasing the model cage from various heights, changing its speed (and thus energy) as it hits the floor. They will record both qualitative and quantitative data to show that energy is transferred from the moving cage to the objects with which it collides. **(4-PS3-3)**

Finally, students apply scientific ideas to design, test, and refine a device that converts energy stored in a battery to lift the model cage using a small motor. **(4-PS3-4)** Students generate multiple design solutions **(SEP 6)** to meet the design specifications, lowering and lifting the model Yates cage from the table to the floor, going *"There and Back Again".* **(3-5-ETS1)**

Mathematics Practice and Standards

<table>
<tr><th>Lesson</th><th>Title</th><th>Mathematical Practice</th><th>Measurement and Data Standards</th></tr>
<tr><td>1</td><td>Journey to the Sanford Underground Research Facility
Create a Measurement Tool to Draw a Floor Diagram of the Yates Cage</td><td>MP 5
Use appropriate tools strategically</td><td rowspan="3">3MD.D.8
Solve real world and mathematical problems involving perimeters of polygons, including finding the perimeter given the side lengths, finding an unknown side length, and exhibiting rectangles with the same perimeter and different areas or with the same area and different perimeters.

4 MD.A.3
Apply the area and perimeter formulas for rectangles in real world and mathematical problems.

5MD.C.5.B
Apply the formulas $V = l \times w \times h$ and $V = b \times h$ for rectangular prisms to find volumes of right rectangular prisms with whole-number edge lengths in the context of solving real world and mathematical problems.</td></tr>
<tr><td>2</td><td>A Load to Carry
Make Measurements and Use Data to Estimate the Yates Cage Capacity</td><td>MP 2
Reason abstractly and quantitatively</td></tr>
<tr><td>3</td><td>A Puzzle to Solve
Build a Scale Model Cage with Accurate Dimensions</td><td>MP 4
Model with mathematics</td></tr>
</table>

Science Standards Matrix

Cross Cutting Concept: Energy and Matter			
Lesson	Lesson	Science and Engineering Practices	Disciplinary Core Idea: Energy Performance Expectations
4	**A Soft Landing** Use evidence to relate the speed of the Yates cage to its energy	**SEP 6** Constructing Explanations and Designing Solutions	**4-PS3-1** Use evidence to construct an explanation relating the speed of an object to the energy of that object.
		SEP 1 Asking Questions and Defining Problems	**4-PS3-3** Ask questions and predict outcomes about the changes in energy that occur when objects collide.
5	**Energizing There and Back Again: An Engineering Design Challenge** Design, test and refine a model hoist system for Sanford Lab	**SEP 6** Constructing Explanations and Designing Solutions	**4-PS3-2** Make observations to provide evidence for how energy can be transferred from place to place by sound, light, heat, and electric currents.
			4-PS3-4 Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.
			3-5-ETS1-1 Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost. **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 a problem. **3-5-ETS1-3** Plan and carry out fair tests in which variable are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Materials List

- Teacher Provided Materials

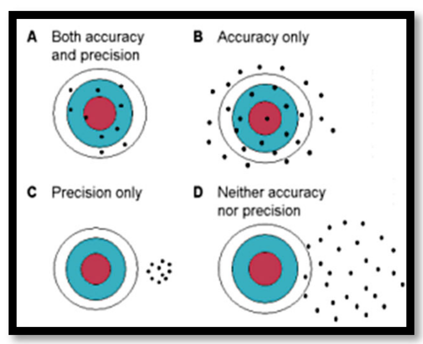
Lesson	Materials Needed
1	**Journey to Sanford Lab** • Task Card • Pre-assessment (Print master) • Blue "Painter's" Tape • Unit cubes ➢ Construction paper for measurement tools ➢ Scissors ➢ Science notebooks (each student)
2	**A Load to Carry** • Task Card ➢ The Sanford Lab cage floor models (from Lesson 1) ➢ Collection of scientist pocket profile cards ➢ Science notebooks (each student)
3	**A Puzzle to Solve** • Task Card • Yates Hoist Diagram Photo • 1 centimeter grid paper (Print master) • Duct tape • Metal bolts (model scientists) • Centimeter rulers ➢ Various Building Materials (*optional*) o cardboard, masking tape, foil, cardstock, scissors, etc ➢ Science notebooks (each student)
4	**A Soft Landing** ➢ Task Card ➢ Model cages (from Lesson 3) ➢ Lesson 4 Supply Kit: pulley, string and J-hook, C-clamp, metric measuring tape ➢ Beans and catch bowl (aluminum) ➢ Metal bolts (from Lesson 3) ➢ Extra bolts and string • Science notebooks (each student)
5	➢ **Energizing There and Back Again: Engineering Design Challenge** Task Card ➢ Model cages (from Lesson 3), all materials from Lesson 4 ➢ Lesson 5 Supply Kit: spool, clothes pins (2), rubber-bands (2), short wooden dowel, binder clips (2) ➢ Motors and D-batteries ➢ Extra rubber bands • Science notebooks (each student)

<table>
<tr><th>Lesson 1</th><th>Journey to the Sanford Underground Research Facility
Create a Measurement Tool to Draw a Floor Diagram of the Sanford Lab Yates Cage</th></tr>
<tr><td>Overview
Standard(s) & Objectives</td><td>Overview
Students watch a video of the <u>Deep Underground Neutrino Experiment</u> and contrast it to the 1930’s video of “<u>Dakota Saga, Getting Underground</u>.” They wonder---how do scientists travel one mile straight down to the underground Sanford Lab? Students begin to explore the hoist system by producing a floor diagram of the cage using a measuring tool, which they create. They find the perimeter of the cage, using their own measurement tool and compare it to other students.

Mathematics
3MD.D.8 Solve real world and mathematical problems involving perimeters of polygons, including finding the perimeter given the side lengths, finding an unknown side length, and exhibiting rectangles with the same perimeter and different areas or with the same area and different perimeters.
4 MD.A.3 Apply the area and perimeter formulas for rectangles in real world and mathematical problems.
5MD.C.5.B Apply the formulas $V = l \times w \times h$ and $V = b \times h$ for rectangular prisms to find volumes of right rectangular prisms with whole-number edge lengths in the context of solving real world and mathematical problems.
Mathematical Practice: Use appropriate tools strategically.
Objectives
✓ Design a new tool, based on the unit cube, to increase the accuracy and precision of their measurements.
✓ Tape out a floor diagram of the Sanford Lab cage with the given dimensions.
✓ Check their shape and measuring tool by comparison with other groups’ floor diagram</td></tr>
<tr><td>Background Information</td><td>The juxtaposition of “old” with “new” is one of the most remarkable aspects of the Sanford Lab. Cutting-edge science experiments (like <u>DUNE</u>) explore our universe in spaces that can only be reached by using a cage and hoist system that was built in the 1930’s (and is largely unchanged). Students watch <u>Dakota Saga: Getting Underground</u> to gain a sense of both the age and the enormity of the Yates hoist system. At one time, this hoist system served the deepest gold mine in North America. Now, the same equipment transports both people and equipment to some of the deepest underground experiments in the world.</td></tr>
<tr><td>Materials</td><td>For each group of 3-4 students:
✓ Journey Task Card
✓ Blue “painter’s” tape to create cage outline on floor</td></tr>
</table>

	✓ Two unit cubes (centimeter) – *extra available on request* ✓ Construction paper (heavy) ---*teacher provided* (used to make their own measuring tool) ✓ Scissors (*teacher provided)* *For each student:* ✓ Pre-assessment (Print master) ✓ Science notebook
Prior Knowledge	Students should have experience measuring *length* using a variety of tools (i.e., rulers, yardsticks, meter sticks, measuring tapes). It will also be helpful if students have a working knowledge of the metric units of length, including the centimeter and the meter. Students will recognize that the shape of the cage is a rectangle. Students may find it useful to use terms like length, width as they create their models. Some students may recognize the importance of a 90° angle at each corner in order to ensure a rectangular shape. For advanced students, an understanding of accuracy, precision and measurement error will help to guide the construction of the floor diagram.
Launch (10-15 minutes)	
Engagement and Communication of Student Expectations	1. Show the Lesson 1 Presentation PowerPoint, which includes a 2-minute video about the proposed Deep Underground Neutrino Experiment. Tell students that the cutting-edge science experiments occur in the former Homestake Gold Mine. Show the 2-minute video of Dakota Saga: Getting Underground . Watch the cage descending mine shaft. Allow students to share comments and reactions. 2. Introduce the Phenomena: In order for people to get to the Sanford Lab, located one mile underground, they must travel using a hoist system developed in the 1930's! Students will wonder, "*How many people can go to the underground lab?*" and *"What kind of motor can carry people safely down a shaft that is one mile deep?"* and *"What kind of container is used to transport the people to the lab?* 3. Remind students that scientists often use models to understand systems and to design solutions. Today, the student's task is to make a life-sized floor diagram using the real dimensions of the cage. Show them a centimeter cube. 4. Tell the students the cage dimensions **width = 200 cm** **length = 400 cm** **height = 200 cm (Grade 5 only)** 5. Ask, "*What type of measuring tool do you need in order to make an accurate floor diagram using painter's tape?*"
Explore (20 to 40 minutes)	
Procedure	1. Tell students that, to tape out the dimensions of the cage, the only tool *they will be given* is a single centimeter cube.

	2. Ask: • Do you think it will be easy or difficult to measure 200 by 400 with this tool? Why? (*tool is too small, you need too many of them to measure, you can make mistakes moving the cube or counting*) • Do you think you could create a tool that would be more efficient and give more precise measurements with less chance of error? 3. Divide the class into groups of three or four students. Distribute the supplies and the Lesson #1 Task Card. Have each group discuss how they might solve the problem and what type of measuring tool they might need to create. They can record their ideas in their science notebooks. 4. Tell students that they may use additional paper, scissors or other common classroom items to make their own measuring tool. (Note: the only items that they should *not* use are a meter stick or ruler). 5. Give groups time to design a measurement tool and to use it to outline the dimensions of the cage on the floor, using blue painter's tape. They use their science notebooks to record any notes, measurements, or calculations. 6. Tell students to measure and/or calculate the perimeter (circumference) of the Sanford Lab cage. Record the perimeter in centimeters (cm) and in meters (m). 7. As students work, circulate first to address any procedural questions and then to observe and to listen to what students are talking about.
Questions	**Driving Questions** *"How can I design a tool to make measurements more efficient, precise and accurate for my floor diagram?"* **Probing Questions** • What problems are you having measuring the dimensions of the cage on to the paper using the centimeter cube? How could you solve it? • Is there a way that you could use the centimeter cube to create a larger unit that would be easier to measure with? • What number of centimeter cubes would be easy to skip count or multiply? (*multiples of 10*) **Teacher Tips:** ✓ Distribute scissors and construction paper to each group, along with two-centimeter cubes and painter's tape. ✓ Each group will need at least a 2-meter x 4-meter space. If a hallway or multi-purpose area is available, it would give groups more space in which to work. **Math Calculation** *Perimeter = sum of all sides* 200 cm + 200 cm + 400 cm + 400 cm = **1200 centimeters** or 2 meters + 2 meters + 4 meters + 4 meters = **12 meters**
Summarize (10 minutes)	

Communicate	1. Ask the students to do a “gallery walk” to look at the model cages. Ask students to note similarities and differences among their cage model and other groups’ models. Encourage students to use their own measuring tool to find the side lengths and perimeters of another group’s model cage. 2. Gather the class together and have groups demonstrate their new measurement tools and discuss any similarities or differences they noticed among the models and tools and measurements. 3. Review any key issues or findings (e.g., *By creating a larger measurement unit, the process was more efficient. By using a multiple of 10, it was easy to skip count and then divide it back into cube units. The measured values found for perimeter reflect the accuracy of the tools.*) 4. If any groups designed a tool that corresponds with a metric unit (e.g., they put 10 cubes together), let them know that they “reinvented” the decimeter.
Terminology and Concepts to Solidify	**Measurement Tool-** Scientists use instruments for obtaining quantities, dimensions, or forces of real-world objects. **Unit of Measurement-** accuracy depends upon a standard quantity whose amount has been set and agreed upon. Examples of measurement units include: kilogram, meter, degrees Celsius, etc. **Model-** Scientists, engineers and mathematicians frequently use a representation of something in the real world, which makes it easier to understand and study. **Measurement Error**-In this context, measurement error is not a mistake—it is simply the difference between an observational measurement and the true or accepted value. All measured values contain “error”.  **Precision-** A precise group of measurements has close agreement with each other. **Accuracy-** The average of an accurate set of measurements has close agreement with the accepted or true value.
Connection to Big Ideas (Phenomena)	The lesson Launch introduces students to the challenge of travelling one mile straight down to an underground laboratory. How can scientists safely travel to the underground lab? In this unit, students will devise their own hoist system using balanced and unbalanced forces. As they begin, they must first gain an understanding of the system by using models. In this lesson, the creation of a new measurement tool is necessary to develop an accurate floor diagram of the Yates cage. The use of measurement tools often arises out of a need to solve a real-world problem or to satisfy human curiosity about the world. Measurement tools are designed improve the efficiency, precision and accuracy of measurements. The accuracy of the tool impacts the measurements. Groups may find that the measured values for perimeter of the model cages will vary depending upon the measurement tool used.

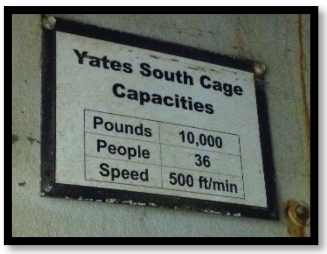
	Scientists and engineers use models to study objects and systems. It is important to make models as accurate as possible to improve their usefulness.
Follow Up/Practice	✓ Students can trade their own measurement tools with other groups and compare their efficiency, precision, and accuracy. ✓ Students can use their measurement tool to measure other objects in the classroom.
Assessment	The Science Notebook can be used as a "self-assessment" or formative assessment for this lesson. Student notebooks should be constructed using the A.C.E. format as indicated on the Lesson #1 Task Card. Note that the Task Card includes "sentence stems" which will help to scaffold student responses. Advanced students may be expected to go well beyond the prompts.

Lesson 2	**A Load to Carry** Make Measurements and Use Data to Estimate Human Cage Capacity
Overview Standard(s) & Objectives	**Overview** *Students ask the question, "How many people can the Yates cage safely transport to the underground laboratories?" Students estimate cage capacity by calculating the area of the cage (or volume in Grade 5) using their floor model. Then, students collect data about the average size of an adult, using profile cards of Sanford Lab scientists to create their own*

	recommendation for the number of people who can be transported in the Yates cage. **Mathematical Standards** **3MD.D.8** Solve real world and mathematical problems involving perimeters of polygons, including finding the perimeter given the side lengths, finding an unknown side length, and exhibiting rectangles with the same perimeter and different areas or with the same area and different perimeters. **4 MD.A.3** Apply the area and perimeter formulas for rectangles in real world and mathematical problems. **5MD.C.5. B** Apply the formulas $V = l \times w \times h$ and $V = b \times h$ for rectangular prisms to find volumes of right rectangular prisms with whole-number edge lengths in the context of solving real world and mathematical problems. Students will ✓ Calculate the area (or volume in grade 5) of the Sanford Lab cage using measurements of length and width (and height). ✓ Estimate the typical area or volume of a Sanford Lab scientist given "Profile Cards". ✓ Estimate the maximum human capacity of the Sanford Lab cage and defend their estimate using mathematical evidence.
Background Information	Answers to real-world problems often differ from exact mathematical computations. For example, in the Sanford Lab cage problem, the size of the unit (i.e., scientist) will vary. There is also a difference between the number of humans the cage can theoretically hold and the number it can hold *comfortably*. The realistic issue of personal space is important! Sometimes in real-world problems, there are design constraints which must be considered. For instance, the Sanford Underground Research Facility has a constraint for the number of people that can be underground at any given time related to the *time* it would take to evacuate in the event of an emergency. For this activity, the only constraint is the *space of the cage* (as related to its area or volume). The capacity of the cage is not actually limited by volume since its height (2 meters) is more than a typical human's height (approximately 6 feet 7 inches). The weight of the people is not a factor in determining capacity. Allowing students to make decisions and use a variety of strategies while solving real-world problems, such as this, will help them define and solve problems much like scientists and engineers.
Materials	*For each Group of 3-4 Students* ✓ Sanford Lab cage floor diagram from Lesson 1 ✓ collection of 12 Sanford Lab profile cards ✓ centimeter grid paper (Print master) *For each student:*

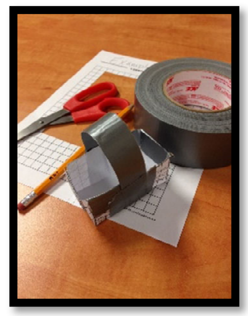
	✓ Science notebook
Prior Knowledge	Students should understand the concepts of area (grade 3 and 4) and volume (Grade 5). Familiarity with the metric units of centimeters and meters will be helpful to students. Remind students of the mathematical strategy of "tiling", which will be helpful to them when they estimate the area that a human would occupy in the cage.
Launch (20 minutes)	
Engagement and Communication of Student Expectations	1. Show the Lesson 2 Presentation PowerPoint, which includes the first few minutes of the Science Friday video. Ask students to guess the number of people in the cage shown in the video. 2. Say to students: *"Imagine that you are in charge of planning the employee schedule at the Sanford Underground Research Facility. You can only send down as many people at a time as the cage will hold safely and comfortably."* How many people do you think will fit in the cage at one time? How could you figure this out? What type of information do you think you would need? 3. Ask students to turn and talk to a neighbor to discuss these questions. Ask several partners to share their ideas.
Explore (35 minutes)	
Procedure	1. Show students one of the profile cards and review the information it contains. How could this information help you estimate the number of people that will fit inside the cage? 2. Allow students to organize themselves into the same groups from Lesson 1 and give each group a collection of profile cards. Encourage students to carefully read each card to gain evidence to support their estimation. 3. Tell groups to formulate a plan for estimating the number of people that can be transported. Remind students to record their plan in their science notebooks. 4. Tell students that there is more than one way of approaching this problem and more than one strategy that can be used to make an evidence-based claim. Allow each group to develop their own strategies. * Strategies students might use (accept any as valid approaches): • Calculate the area of the cage (and volume in Grade 5) • Estimate the average size of scientist. • Use largest person on profile card as unit. • Use someone from their group as unit and round either unit size (up) or final answer (down) to compensate. • Tiling approach, where they create a measurement unit equal to one person and lay it down repeatedly. • Calculate area of Yates cage and divide by unit. • Consider personal space "bubble" and round down for final answer.

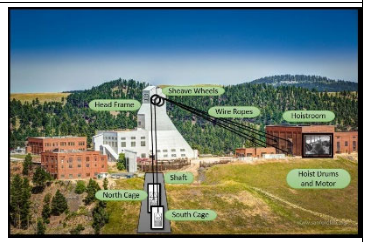
	Mathematical Calculations: *Area = length* x *width* (400 centimeters) x (200 centimeters) = **80,000 cm^2** or (4 meters) x (2 meters) = 8 **m^2 (square meters)** *Volume = length* x *width* x *height = (area of base)* x *height* (200 cm) x (400 cm) x (2oo cm) = **16,000,000 cm^3** or (2 m) x (4 m) x (2 m) = **16 m^3 (cubed meters)**
Questions	**Driving Question** *How can I use mathematical estimation and my knowledge of area and volume to determine the number of scientists that can be comfortably transported in the Yates cage?* **Probing Questions** • Are all the scientists the same size? • Are there sizes of scientists that are not represented in your sample of profile cards? What does that mean for this problem? *(need to come up with a generalization that will work for any group of scientists)* • What would be a good "person size" to use for your calculations? How could you figure that out? • Would you use the entire area of the cage to hold people? Explain. *(you might want to allow some space between people so people are not touching)* • Does the duration of the trip make a difference? *(people might stand being less comfortable in a short trip, such as several stories in an elevator but not in a longer trip in the underground cage)*
Summarize (5 minutes)	
Communicate	**Sharing and Discussion** Have each group share its answer and briefly explain the strategy they used. Record answers on the board. Note similarities and differences among the groups' answers and discuss what might have led to the different results. Ask, "Why did we solve this problem using a model rather than the actual Sanford Lab cage?" *(we would have to go to the lab to use the actual one; more groups can solve the problem simultaneously; less expensive and complicated than holding the actual cage to do experiment).* Make connections to the use of models in the work of scientists and engineers. Encourage students to share and compare their evidence in support of their estimation.
Terminology and Concepts to Solidify	**Area-** The product of the length times the width equals the amount of space inside the boundary of a two-dimensional object. Area is expressed in square centimeters (cm^2) and square meters (m^2). **Volume** (Grade 5) The product of length x width x height equals the amount of space inside the boundary of a three-dimensional object. Volume is expressed in cubic centimeters (cm^3) or cubic meters (m^3). **Load-** In an elevator system, a load is a mass or weight supported by something else. An elevator's load is the cage and its contents.

Connection to Big Ideas (Phenomena)	Real-world problems are usually open-ended, with many possible solutions. Students should be encouraged to use mathematical and scientific evidence to support their estimation. Discussion about different strategies leading to different conclusions will help students to recognize that evaluating multiple approaches can result in stronger solutions. As students utilize their model cage to develop their load estimate, they will understand that scientists and engineers use models as a more efficient way to perform experiments and solve problems.
Follow Up/Practice	The Sanford Lab has determined that the capacity of the Yates Cage is 36 people and a maximum of 10,000 pounds. From these figures, one can see that the number of persons transported is **not** limited by the weight. If students "do the math", they can estimate the average weight of a person and then multiply to find the maximum capacity based on weight. Students should agree that the ***space*** in the cage limits the capacity, rather than the *weight*.  Students may also find it interesting that the ***breaking strength*** of the metal ropes that support the cage is 275,000 pounds!
Assessment	The Lesson #2 Task Card includes sentence stems to support students in answering the question, citing evidence, and explaining their reasoning in the science lab notebook. Check for mathematical accuracy: *Area = length* x *width* (400 centimeters) x (200 centimeters) = **80,000 cm^2** (4 meters) x (2 meters) = 8 **m^2 (square meters)** *Volume = length* x *width* x *height OR (area of base)* x *height* (200 cm) x (400 cm) x (2oo cm) = **16,000,000 cm^3** (2 m) x (4 m) x (2 m) = **16 m^3 (cubed meters)**

Lesson 3	**A Puzzle to Solve** Construct a Scale Model Cage with Accurate Shape and Dimensions
Overview Standard(s) & Objectives	**Overview** *Students analyze a diagram of the Yates hoist system and sketch the system components in their science notebooks. Students construct a small-scale model of the cage that retains accurate relative dimensions using centimeter grid paper. Then, students build a 3-dimensional scale model of the cage (with a handle) from the materials provided.* **Mathematics Standards:** **3MD.D.8** Solve real world and mathematical problems involving perimeters of polygons, including finding the perimeter given the side lengths, finding an unknown side length, and exhibiting

	rectangles with the same perimeter and different areas or with the same area and different perimeters. **4 MD.A.3** Apply the area and perimeter formulas for rectangles in real world and mathematical problems. **5MD.C.5. B** Apply the formulas $V = l \times w \times h$ and $V = b \times h$ for rectangular prisms to find volumes of right rectangular prisms with whole-number edge lengths in the context of solving real world and mathematical problems. **Mathematical Practice:** Model with mathematics **Objectives:** Students will ✓ Use a diagram to sketch a 2-dimensional model of the Yates hoist system with accurate labels. ✓ Draw a 2-dimensional scaled diagram of the Sanford Lab cage on centimeter grid paper which can be folded to create a model cage, with a total base area of less than 72 cm^2. (Grade 5 total volume less than 432 cm^3. ✓ Build an accurate scale model of the Sanford Lab cage to accommodate at least 10 "scientists" (bolts), using materials provided.
Background Information	In this lesson, students will use and/or create several different models, all related to the Yates hoist system. This variety will offer an opportunity for students to realize that scientists and engineers employ many different types of models, including drawings, diagrams, computerized animations, and even 3-dimensional renderings. In the previous lesson, a life-sized floor model was used to estimate cage capacity. Now, a smaller scale model cage will be created for incorporation into a table-top model of the hoist system. Different scientific or engineering goals require different types of models.
Materials	*For each Pair of Students* ✓ Yates Hoist System Photo ✓ "**A Puzzle to Solve**" Lesson #3 Task Card ✓ Paper printed with 1 centimeter grid (PRINTMASTER) ✓ Duct tape ✓ Baggie of six metal bolts (model scientists travelling to the underground labs) ✓ Pencils, Scissors – *teacher-provided* *For each student:* ✓ Science notebook
Prior Knowledge	Students should be familiar with the terms length, width and area. Students will need to be encouraged to recognize the relative dimensions of the Yates cage (the length is twice as long as the width). Students

	should know that area can be calculated as the product of the length times the width. The unit for area will be in cm^2 or m^2.
Launch (15 minutes)	
Engagement and Communication of Student Expectations	Show the Lesson 3 Presentation PowerPoint. Distribute the Yates Hoist System photo to each group (or access the online puzzle). Have student teams complete the puzzle or examine the photo. Then, ask students to sketch the diagram in their science notebooks and note the location of the following components: headframe, sheave wheels, hoistroom, north cage, south cage, shaft, metal ropes. Point out to students that scientists often use models to study systems. The puzzle/photo and their sketch are examples of 2D models. Today, students will be making a 3-dimensional model of a Yates cage to be used for all remaining lessons.
Explore (30 to 50 minutes)	
	 1. Distribute **A Puzzle to Solve** Lesson #3 Task Cards and supplies. 2. Remind students that they have already made a "life-sized" floor diagram of the Yates cage (in Lesson 1). 3. Coach groups toward an understanding that the width of the "real" cage is half the length (and their model must retain this relationship). The height of the cage is equal to the width. 4. As students sketch a scaled version of a 2D base of the model, encourage them to think about the size of the model cage necessary to accommodate six metal bolts (representing scientists). 5. Remind students of the size constraint: ✓ Grade 3 and 4: base area of their scale model = less than 72 cm^2 ✓ Grade 5: volume = less than 432 cm^3 **Teacher Tip:** The teacher can decide if students should work individually or with a partner to create the scale models. The materials are inexpensive (grid paper) and the work could easily be completed by each student in collaboration with partners or group.
Questions	**Driving Question:** *"How can I use my knowledge of area (and volume) to construct a small, sturdy scale model of the Yates cage within the size constraints?"* **Probing Questions** • What are the dimensions of the real-life Yates cage? • What is the relationship between the width of the Yates cage and the length of the Yates cage? (*the length is twice as long as the width*) (*the width is equal to the height*) • What are some possible sizes of an accurate scale model? *Any 2:1 ratio will be an accurate scale model: 4 cm* x *8 cm, 5 cm* x *10 cm, 6 cm* x *12 cm*

Summarize (10 minutes)	
Communicate	Ask students to describe and show their model to group members or to the whole class. Ask students to discuss the process that they used to determine the size of their scaled model. Try to find student models of varying size, to emphasize the fact that there are multiple different ways to create a scale model with accurate size and shape.
Terminology and Concepts to Solidify	Students will label the parts of the hoist system as they make a diagram in their science notebook. It is NOT important that students memorize the terminology. The skill is to accurately draw and label a diagram as an example of scientific modelling. 
Connection to Big Ideas (Phenomena)	Upper elementary students should understand that conceptual models are helpful for a wide variety of reasons, including describing complex systems or for working with objects that are too big or too small to study directly.
Follow Up/Practice	Scientists often use accurate scale models. Students could think about other systems that are very large (or very small) which may need a scale model. (examples include: solar system, the atom, city maps, globe, etc.)
Assessment	The teacher should review the Yates hoist diagram in the science notebooks and check for accuracy regarding parts and labels. Next, verify that the small-scale model cage retains the relative dimensions of the Yates cage (the length is twice the width). If a student has created a model cage that is not rectangular, ask the student to take a close look at the "life-sized" cage model which they created in Lesson 1 for comparison. The science notebooks should include student responses to A.C.E. the Driving Question. In this lesson, the A.C.E. response should include both calculation and measurement, as students use evidence to show that their small-scale model is accurate in size and shape and meets the criteria (sturdy and smaller than 72 cm^2 in area).

Lesson 4	**A Soft Landing** Use evidence to relate the speed of the Yates cage to its energy, in motion and after collisions.
Overview Standard(s) & Objectives	**Overview** Many times, each day at the Sanford Underground Research Facility, the Yates cage moves up and down a shaft that is over one mile deep to deliver people and equipment safely to the 4850-foot level. The speed of the real Yates cage is carefully controlled by the hoist operator. Students will use evidence to show that the speed of their own model cage is related to its energy by making predictions about the change in energy that will occur when the cage collides with the floor from various heights. **Science Standards** **4-PS3-1** Use evidence to construct an explanation relating the speed of an object to the energy of that object. **4-PS3-3** Ask questions and predict outcomes about the changes in energy that occur when objects collide. **Science and Engineering Practice:** **SEP 1:** Asking Questions and Defining Problems **SEP 6:** Constructing Explanations and Designing Solutions

	Crosscutting Concept: Energy/Matter **Objectives** ✓ Find evidence about the speed and energy of the model cage as it is lowered to the floor from various heights. ✓ Make predictions about the change in energy of the model Yates cage as it collides with the floor. ✓ Create a data table to record measurements and observations
Background Information (Crosscutting Concepts)	The science standards in this unit are all undergirded by two quantities: energy and matter. Students begin to build connections between the two quantities when they realize that the speed of an object is related to its energy. Note that speed *itself* is not energy. In order to avoid common misconceptions regarding the nature of energy, the topic is treated only in general terms in late elementary grades. The focus of classroom discussions about energy should be on the transfer of energy into, out of and within the system being studied. The total change in energy in any system is always equal to the total energy transferred into or out of the system. Students explore these connections when they consider the transfer of energy between two colliding objects. In this investigation, the model cage can be considered as transferring all its energy to the beans in the bowl. The motion of the beans is a measure of the energy that has been transferred from the cage to the beans.
Materials	*For each pair of students* ✓ **A Soft Landing** Task Card ✓ Model cage (from Lesson 3) ✓ Model scientists from Lesson 3 (bag of bolts) ✓ Lesson 4 Supply Kit: Pulley, string, J-hook, C-clamp, long wooden stick ✓ Small bowl of dried beans *For each student* ✓ Science Notebook
Prior Knowledge (DCI Progression)	For many students, this activity will be one of the first times that they have considered the topic of *energy* from a scientific perspective. Students may have developed an association of energy with phenomenon like sound, light, heat or electricity. In this activity, students will learn that the faster an object is moving, the more energy it possesses. A collision between two objects results in a change of energy, as energy is transferred from one object to another. In this lesson, the energy of the cage is transferred to the beans in the bowl, as the cage comes to an abrupt halt. Collisions also transfer some energy to the surrounding air, which can produce a sound. Students can make both qualitative and quantitative observations (by counting displaced beans and by listening for a change in the volume of the sound made from the collision). Students should be able to create fair tests in which variables are controlled and the number of trials is considered. They will make observations and

	measurements to produce data which can be used to make predictions about what would happen if a variable is changed.
Launch (15 minutes)	
Engagement and Communication of Student Expectations	1. Make a career connection! Show students the Lesson #4 Presentation PowerPoint. Students watch a video with an interview of Sanford Lab hoist operator, Cindy McCormick. Tell students that a hoist operator needs to understand energy and motion so that they can ensure safe operation of the hoist system. 2. Tell students that today, they will need to ask questions, predict outcomes, and gather evidence to relate the speed of their model Yates cage to its energy. Students will need to make careful observations to gather evidence about the change in energy that occurs when the model cage hits (collides with) the beans in the bowl on the floor.
Explore (30 to 50 minutes)	
  Procedure	1. Distribute materials and **A Soft Landing** Task Cards. 2. Students assemble the system as indicated in the photo on the Task Card. 3. Students place the bowl filled with beans directly under the model cage so that the cage lands in the middle of the bowl. 4. Students add six metal bolts to the cage (representing scientists) to give the cage enough mass to move the beans in the bowl. 5. Students measure the height of the cage and release it. Students should record their observations as cage hits the beans. Each group can decide what evidence they wish to collect. Possible evidence may include: ✓ Counting the beans that are propelled out of the bowl. ✓ Noting the volume of the sound produced when the cage hits the beans. ✓ Measuring the distance that the beans travel away from the bowl. ✓ Noting the size of the depression made in the beans. 6. Students may create their own data tables. Teachers may want to suggest this format to teams that need extra support:

Trial	Height of cage (cm)	Predictions	Observations and Measurements
#1			
#2			
#3			

Questions	**Driving Questions**

	"What evidence can I use to relate the speed of the model cage to its energy? How does this energy change when the cage collides with the floor?" **Probing Questions** • How does the release height relate to the speed of the cage? *(the greater the height, the faster the cage moves)* • What do you notice about the sound that is produced when the model Yates cage collides with the beans? (*the collision at faster speeds results in a louder sound)* • How does the number of beans outside of the bowl relate to the energy of the model cage? (*more energy results in more beans outside of the bowl)* • How does the distance that the beans travel away from the bowl relate to the energy of the cage? *(the beans travel farther when the cage collides with more energy)*
Summarize (10 minutes)	
Communicate	After the students complete several trials, focus their attention on the two driving questions. Challenge the students to use direct observations and measurements from their investigation as they A.C.E. the Driving Questions in their science journals. One of the most important aspects of a scientific investigation is the communication of results. During this lesson, students should understand that. ✓ Scientific investigations result in evidence. ✓ Scientific evidence may be an observation or a measurement. ✓ Scientific evidence is recorded in a data table, with appropriate headings, labels, and units. Ideally, students will design their own data tables in their scientific journals. The skill of communicating data in the form of a table is an essential component of planning and conducting a scientific investigation.
Terminology and Concepts to Solidify	**Speed**—the rate at which an object covers a distance. **Energy**—the ability to "do work". Objects have energy due to their motion, their position, and their mass. **Change in Energy**—energy can be transferred from place to place. Energy can change form.
Connection to Big Ideas (Phenomena)	Students continue to wonder about the challenge of lifting and lowering the Yates cage safely over a vertical distance of more than a mile. Ask students to think about the relationship between the energy of an object and its speed. *Is it easier to move the Yates cage slowly down the shaft or quickly*? Why does the Hoist Operator ensure that the cage is moving slowly when it reaches its destination?

Follow Up/Practice	Students have many shared experiences which can be used to reinforce the two performance expectations in this lesson. Recognize that the speed of an object is related to its energy but *is not the same as* its energy.
Assessment	The **A Soft Landing** Task Card is intended to guide students in the two Science and Engineering Practices highlighted in this lesson. As you review the student notebooks, look for evidence that the students are making accurate predictions based on their understanding of the relationship between the motion of the cage and the amount of energy that will be transferred to the beans in the bowl. Check the Data Table to see if the students have recorded evidence which supports their explanation which relates the speed of the cage to the energy of the cage.

Lesson 5	**Engineering Design Challenge** Design, Test and Refine a Model Hoist System to lower and lift the Yates cage using energy transfer and conversion
Overview Standard(s) & Objectives	**Overview** *Student teams will apply their knowledge of energy transfer to design a device to lower and lift the model cage, modeling the Yates hoist operation. Students will test and refine their design until they meet the engineering specifications of the design challenge. Students will demonstrate their system design for the class and calculate a TBA Score (There and Back Again Score).* **Science Standards** **4-PS3-2** Make observations to provide evidence for how energy can be transferred from place to place by sound, light, heat, and electric currents. **4-PS3-4** Apply scientific ideas to design, test, and refine a device that converts energy from one form to another. **Engineering Design Standards** **3-5-ETS1-1.** Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost. **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. **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. **Science and Engineering Practice:** Constructing Explanations and Designing Solutions **Crosscutting Concept:** Energy/Matter

	Objectives ✓ Use the engineering design process to define a problem and then design, test, and refine a hoist system to lower and lift a model cage, while simultaneously maximizing the mass and minimizing the time to go "there and back again".
Background Information	An Engineering Design Challenge invites students to take an integrated approach to problem solving that incorporates not only science or math content knowledge but also creativity, critical thinking, problem solving and open-ended questioning. A well-constructed design challenge has multiple solutions and encourages students to take risks with diverse approaches to the problem. The teacher sets the stage for the Engineering Design Challenge by helping students to ask questions and define the problem. The classroom culture should welcome brainstorming and exploration of solutions while meeting the challenge constraints. An emphasis on the *process* rather than the *product* will keep students focused on their job as engineers who design solutions, rather than on competition or right/wrong answers to a problem. This focus of this engineering challenge is energy transfer and conversion. The challenge will require them to apply their scientific ideas about energy to design, test and refine a device (model hoist system) that uses energy to lower and lift the model cage. The design challenge requires the students to maximize both the mass of the cage and the distance that it travels. Students will find that it requires more energy to lift a heavier object than a light one. Students will observe that it requires more energy to lift the object over a greater distance.
Materials	*For each pair of students:* ✓ **Energizing There and Back Again, Engineering Design Challenge** Lesson#5 Task Card ✓ Lesson 5 Supply Kit: clothes pins (2), rubber bands (2), medium wooden stick, spool, binder clips (2) ✓ A motor with battery ✓ Lesson #4 Supply Kit: C-clamp, long wooden stick, J-hook with string, pulley, metric measuring tape ✓ kidney beans and bowl ✓ Model cages made in Lesson 3 ✓ Metal bolts from Lesson 3 and extra bolts *For each student* ✓ Science notebook
Prior Knowledge	Student will use the results of their scientific investigations (Lesson 4) to design a model hoist system. Students should be encouraged to reflect on the observations which were recorded in their lab notebooks in Lesson 4, drawing upon an understanding of energy, motion and energy transfer. Students should recall that an object's speed is related to its energy. (4-PS3-1). They know that a change in energy occurs when objects collide. (4-PS3-3)

Launch (15 minutes)	
Engagement and Communication of Student Expectations	Begin the Engineering Design Challenge by telling the students that they will become "engineers" today! Show the Lesson 6 Presentation PowerPoint, which contains a video taken from above the work deck of the Yates cage. The goal today is to design a model hoist and cage system that will safely deliver the Sanford Underground Research Facility scientists (represented by metal bolts) to the 4850 Ft. Level (floor) and back to the surface (table). They will need to use at least one type of energy conversion to lower and lift their model cage. Teams will calculate the "There and Back Again Score" (TBA Score) for each device, using this formula: **10 x (# bolts) + total distance travelled (cm) = TBA Score**
Explore (30 – 50 minutes)	
Procedure	*During the design challenge, encourage students to continue to refer to the Engineering Design Process as they approach their challenge.* ***ASK-PLAN-BUILD-TEST-REFINE*** **ASK** --as a whole group, prompt students to ask questions about the design challenge. Using the classroom board, write the student's questions about the challenge and provide answers verbally: • What supplies can we use to design the hoist system? *(Only the materials in the construction kit and from Lesson 4, Note: you could offer the students a small amount of duct tape (10 cm) if they need it for their design.)* • How much time before we must be ready to test our designs? *(The scientists are eager to begin their work at the Sanford Lab as soon as possible! Your construction team should plan to design and build your device within 20 - 40 minutes. We will then test each group's hoist system together as a whole class.)* *NOTE*: Encourage the students to continue to ask questions that clarify the design constraints. Engineers work to meet specific constraints which are determined by the demands of the project. The Engineering Practice requires that students "define problems". For this challenge, the design constraints are: 1. Model cage must move vertically from the table height to the floor (bowl of beans) and back up again. 2. The distance of the round trip (that the cage actually travels) should be measured in centimeters and recorded for the TBA score. *3.* Students must devise a way to move the cage both down and up *without touching the cage or the string.* Students may touch the device when switching the direction of the cage motion. Students may hold the motor while the hoist is operating. 4. Students should try to maximize the number of scientists (metal bolts) in the cage.

5. Soft landing: the cage must land without causing any beans to move out of the aluminum tin.
6. Teams will be asked to calculate a "There and Back Again" Score (TBA Score) for their device:

10 x (#bolts) + Total Distance Travelled (in cm) = TBA Score

PLAN: Teams obtain materials and begin to brainstorm solutions. Each member begins by creating a sketch of their ideas in their science notebooks. Remind students to use their data from the previous investigation (Lesson 4), and to incorporate their scientific findings into their plans.

BUILD: When the team is ready, students should begin to build their model hoist system using any of the items in the Construction Pack. The packs contain more materials than the team will need. Teams do not need to use all of the pack components. Remind teams of the design constraints as they work.

TEAM TEST: Encourage teams to test their model frequently as they build, using the stopwatch provided in the pack. Encourage teams to calculate the "There and Back Again" Score (TBA Score).

10 x (#bolts) + Total Distance Travelled (in cm) = TBA Score

*The goal is to maximize the TBA Score. Any score over **50** is considered a "successful" hoist!*
Note: students will find that adding bolts to the cage makes it more difficult to achieve the other constraints of distance lifted and lowering without spilling the beans.

Whole Group "TEST": When all teams have their models ready to test, call the whole class together. Ask for a volunteer team to go first. Before testing the model hoist system, have a team member describe the device, paying special attention to the balanced and unbalanced forces in their system. Then, the team will demonstrate their model by allowing the cage to descend and to ascend. The teacher will hold the stopwatch and announce the time for each team's cage round trip, *there and back again*. Have students record the time (in seconds) and the number of scientists (metal bolts) safely delivered to the 4850 ft. Level (floor) and back to the surface (tabletop) for each team on the classroom board. Calculate the "There and Back Again" Score for each team, and the average score for the class.

Team Name	Number of Scientists (# metal bolts) = **S**	Distance travelled down (cm) = **D**	Distance travelled up (cm) = U	"There and Back Again" Score **S + D + U =** **TBA Score**

Class Average				

TEACHER TIP: you may need to wait until the next class period to begin the refine and re-test part of the Engineering Design Process.

REFINE: Give students an opportunity to look carefully at each group's model hoist system. Encourage them to ask each other questions about their designs. Then, give each team 10 minutes to make modifications to their own systems. Reinforce the idea that there are many ways to design a system that meets the constraints and many ways to address this challenge!

RE-TEST: As a whole group, allow each team to demonstrate their revised model. Prior to the re-testing, be sure to ask a team member to describe the changes that they made to their design and explain why they made those changes, using evidence based on their observations from the classroom tests. In the whole group discussion, encourage students to describe the balanced and unbalanced forces in their models.
Recalculate the class average "TBA Score" ---did the **refine** process improve your results?

Questions

Driving Question
"How can I design a model hoist system using energy conversions to transport scientists to the Sanford Underground Lab and back again?"
Probing Questions
- "What is the energy conversion being used by your device?" *(the battery in the motor is being used to turn the spool which results in the movement of the cage.)*
- How is the energy of the system changing as the cage moves down compared to moving up? (*energy required to lift the cage is greater than the energy required to lower the cage*)
- What factors do you need to consider getting your cage to move down slowly for a soft landing? (*cage must be slowed by some mechanism—perhaps counter-weights or friction or using motor to control movement)*
- How can you make the motor to be more efficient in the energy transfer? (*Minimize friction on device*.)

Summarize (10 minutes)

Communicate

During the first and second rounds of testing, allow multiple students from each team to describe their model, their design process and their modifications and revisions. As you interact with the teams during the testing, ask probing

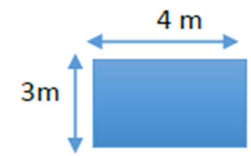
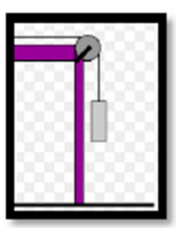
	questions which cause them to think about both the engineering design process and the science of their working model.
Terminology and Concepts to Solidify	**Engineer/Engineering-** An engineer designs solutions to human problems by creatively applying principles of science, mathematics or technology. **Engineering Design Process-** Engineers use an iterative cycle of steps to solve a human or societal problem. **Constraint-** Realizable solutions always have realistic limits. The constraint is generally framed in terms of materials, cost, time or energy available for the engineered solution. **Refine/Redesign-** Engineering is a cycle of iterative improvement. The process of changing or improving a design solution after testing all or parts of the system is called refining or redesigning. **Test-** The best design result when testing is frequent and systematic. A good test is a controlled measurement of a system to determine success in meeting design goals. **Pulley-** In this investigation, students use a pulley wheel to change the direction of a force or pull on an object. In this application, the use of the pulley can be compared to the fulcrum in a balance.
Connection to Big Ideas (Phenomena)	Engineers use science and technology to solve problems and design solutions. The Engineering Design Process is cyclical and adaptable. Students are given a design challenge, and then begin to look for solutions by **asking questions**. Ideally, students will brainstorm with their teams and create detailed **plans**. As teams begin to **build** or create solutions, **testing** and **refining** begin. Students will naturally work toward a solution while utilizing multiple stages of the Engineering Design Process, often simultaneously. **ASK-PLAN-BUILD-TEST-REFINE**
Follow Up/Practice	If time allows, students could be challenged to incorporate more sophisticated pulleys or ramp systems into their model. Students can continue to refine-test-redesign their systems to improve the journey *there and back again* and increase their TBA Score.
Assessment	When assessing an Engineering Design Challenge, the focus is on the *process* rather than the *product*! Teams may or may not be able to achieve a high “TBA Score” yet may still be meeting or even exceeding the Engineering Design Standards. Students may also have mastered the content standards, without successfully meeting the design challenge goal. Students should be encouraged to take risks with their designs, to consider innovative solutions to the problem and to extend their exploration beyond the classroom setting. It is very important to eliminate unnecessary judgements or comparisons of team designs. Skilled teachers find ways to affirm the process that a student has undertaken, even when the outcome doesn’t “work” the way that a student may have wished. After the challenge has concluded, encourage students to A.C.E. the Driving Question using the prompts on the Lesson #5 Task Card. If students did not have time for the **Refine/Re-test** portion of the lesson, they may use their science

	notebooks to identify ways that they would have improved their design or offer different ways that they would change their design if given different constraints.

Print Masters

There and Back Again Unit Pre/Post-Assessment

Answer the following. You may include illustrations to help with your explanations.

Scenario	Question	Explanation
Jenny and Bob are trying to draw a scale model of a swimming pool. The real pool is 20 meters wide and 40 meters long. Jenny and Bob each draw their scale models.	Circle the person who has drawn a more accurate scale model. **Bob**  Bob's scale model is 3 meters wide and 6 meters long. **Jenny**  Jenny's scale model is 3 meters wide and 4 meters long.	Explain why this person's scale model is more accurate. What evidence can you give to support your selection?
Jenny and Bob are looking at a pulley with an object attached by a string. The object is dropped from two different heights. Jenny and Bob each make different predictions. 	Circle the most scientifically correct prediction. **Jenny says**, "The object will hit the ground with the same amount of energy when dropped from any height." **Bob says,** "The object will hit the ground with more energy when it is dropped from a greater height."	**Describe an experiment** that you could do that would provide evidence to support your prediction. What evidence could you measure or observe about the energy of the object when it hits the ground?

There and Back Again
Task Card Lesson #1

Lesson #1 Journey to the Sanford Underground Research Facility

Driving Question
"How can I design a tool to make measurements more efficient, precise and accurate for my floor diagram?"

Supplies
Blue "painter's tape", centimeter cube, paper, scissors

The Goal
Create an accurate "real-sized" floor diagram of the Yates elevator cage, using tape on the floor, a centimeter cube and a new tool which you design.

What We Know
The base of the Yates cage has a length of 400 centimeters and a width of 200 centimeters.

Think Like a Scientist
- ✓ Scientists often design new measuring tools for specific purposes.
- ✓ You will need to create a new measuring tool in order to make an accurate floor model of the Yates cage.
- ✓ The floor diagram must be the same shape and the same size as the real Yates cage. How will you be sure? (hint: perimeter and area)

A.C.E. the Driving Question

Answer the Driving Question
The process that I used to design a new tool to make the floor diagram of the Yates cage is

____

____

Cite your Evidence

Evidence #1 Using my new tool, I know that the floor diagram is the same *shape* as the Yates cage because

____

____

Evidence #2—Using my new tool, I know that the floor diagram is the same *size* as the Yates cage because

____

____

Evidence #3---The perimeter of the floor diagram is ____centimeters and ____meters.

Explain your Reasoning
The new measuring tool made my measurements more efficient, precise and accurate because

____

____

There and Back Again
Task Card Lesson #2

Lesson #2 --A Load to Carry

Driving Question
"How can I use mathematical estimation and my knowledge of area (and volume in Grade 5) to determine the number of people that can be safely and comfortably transported in the Yates cage?"

Supplies
Sanford Lab profile cards, Yates cage floor diagram

The Goal
As a team, determine the number of people that could be transported in the Yates cage. Be prepared to defend your answer!

What We Know
Use information from the Sanford Lab profile cards, the size of the Yates cage and any other information that your group decides is important.

Think Like a Scientist
- ✓ Brainstorm ideas with your group to **develop a strategy** for making an estimate.
- ✓ Record mathematical and scientific evidence about the number of people who can be transported in the cage.
- ✓ **Determine a number** based on your evidence.

Answer the Driving Question

Based on our evidence, we estimate that ________people can travel safely and comfortably in the Yates cage.

A.C.E. the Driving Question

Cite your Evidence

Evidence #1—The average person needs at least ______space because
____
____

Evidence #2—I considered the comfort of the people in the cage because
____
____

Evidence #3—I considered the safety of the people in the cage because
____
____

Explain your Reasoning

I agree with the estimate because
____
____

There and Back Again
Task Card #3

Lesson #3 A Puzzle to Solve

Driving Question
"How can I use my knowledge of area to construct a small, sturdy scale model of the Yates elevator cage with a total base area of less than 72 cm^2?"

Supplies Yates photo, centimeter grid paper, mini-scientists (bolts), duct tape, etc.

The Goal Create a small, sturdy 3-D model of the Yates cage. ***Use duct tape to add a handle for use in future lessons.***

What We Know
The Yates cage has a rectangular shape. The real cage is 200 cm wide and 400 centimeters in length. Your model cage must have a base area less than 72 cm^2. The real Yates cage has a height of 200 cm.

Think Like a Scientist
- ✓ With your team, decide on the size of your model.
- ✓ Draw your model cage on the centimeter grid paper. Be sure to draw your model so that it will form a box with four sides. Cut and fold and tape the model cage.
- ✓ *Check:* Is the model a rectangle with the same shape as the real Yates cage? Measure the width and compare it to the length.
- ✓ *Check:* Is the base area less than 72 cm^2? Is the volume less than 432 cm^3.

A.C.E. the Driving Question

Answer the Driving Question
Explain how you made an accurate, sturdy, scale model of the Yates elevator cage.

Cite your Evidence
Evidence #1--The model is accurate in size because

Evidence #2--The model is accurate in shape because

Evidence #3—the model is sturdy because

Explain your Reasoning
The process that I used to make a model was

Accurate models and measurements are important to scientists because

There and Back Again
Task Card Lesson #4

Lesson #4: A Soft Landing

Driving Questions: *"What evidence can I use to relate the speed of the model cage to its energy? How does this energy change when the cage collides with the beans on the floor?"*

Supplies: Supply Kit (C-clamp, wooden stick, dowel, pulley, string with J-hook), bowl of red beans, model Yates cage (from Lesson 3), model scientists (from Lesson 3), centimeter ruler, centimeter graph paper

The Goal
Use the materials to investigate energy, speed and collisions. Gather scientific evidence to answer the driving questions.

What We Know
The speed of an object is related to its energy. Energy can be transferred from place to place when a collision occurs.

Work Like a Scientist
1. Use the C-clamp to attach the wooden stick to the edge of a table or desk. Connect the pulley to the stick and thread the string with J-hook through the pulley. Attach your model Yates cage to the J-hook.
2. Attach the measuring tape to the desk and floor. Use the metric (centimeters).
3. Place the bowl filled with beans directly below the pulley. Put six bolts (representing scientists) in the model Yates cage.
4. Determine at least three different "release heights". Allow the cage to drop into the beans.
5. Record your observations! *What evidence will you collect?*

Trial	Height of cage (cm)	Predictions	Observations and Measurements
#1			
#2			
#3			

Answer the Driving Question
"How does the speed of the model cage relate to its energy? How does this energy change when the cage collides with the floor?"

____

____

Cite your evidence

Evidence #1—I know that the cage has more energy when it is moving faster because

____

____

Evidence #2— I know that the energy of the model cage changes when it collides with the beans because

____

____

Evidence #3— I know that energy is transferred to the beans because I observed/measured

____

Explain your Reasoning

There and Back Again
Lesson #5 Task Card

Lesson #5 Engineering Design Challenge

Driving Question
"How can I design a model hoist system using energy conversions to transport scientists to the Sanford Underground Lab and back again?"

Supplies

Lesson 5 Supply Kit (spool, clothespins (2), medium dowel, rubber bands (2), binder clips (2)), all materials from Lesson 4 (Supply Kit, model cage, model scientists), extra bolts

The Goal

Build a device to lower and lift your model cage, filled with mini-scientists (bolts) to the underground labs (floor) and back again (table) using energy from a motor.

What we Know

1. The elevator must operate "hands-free" when cage is in motion. You may hold the motor in your hands if you wish. You may adjust the system to switch from lowering to lifting the cage.
2. Students should try to maximize the number of scientists (metal bolts) in the cage and at the same time maximize the total distance travelled.
3. Teams will need to calculate a "There and Back Again" Score (TBA Score).

10 x (#bolts) + Distance Travelled (cm) = TBA Score

Answer the Driving Question

The energy conversion that I used to lower and lift the model cage is

____

Cite your Evidence

Evidence #1— The cage descends slowly and has a soft landing when

____

Evidence #2—The design uses energy from the battery in the motor to

____

Evidence #3— The TBA score for at least three trials is shown in a table

Trial Number	Number of Scientists (# metal bolts) = **S**	Cage Lowering Distance (in cm) = **D**	Cage Lifting Distance (in cm) = **U**	"There and Back Again" Score **S + D + U = TBA Score**

Explain your Reasoning

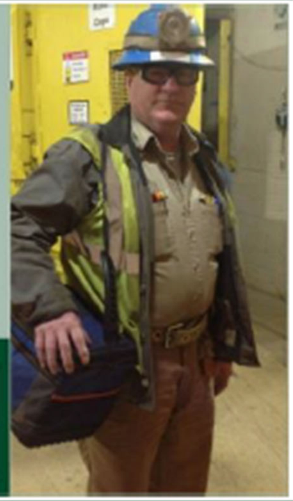
The TBA score shows we met the challenge because

____

THERE AND BACK AGAIN

It takes a lot of hard work to keep the underground lab going! Pack a cooler with your lunch. And, don't forget your reflective vest, hardhat and safety glasses!

People at Sanford Lab
Profile Card



THERE AND BACK AGAIN

Scientists often need to bring extra gear to the underground lab. This scientist carries his backpack in a plastic bag, science equipment in a cardboard box, and a small package down to the lab today!

People at Sanford Lab
Profile Card

THERE AND BACK AGAIN

This scientists carries his gear for the day in a plastic bag. Why? To keep it clean! He will change out of his coveralls and take his gear out of the plastic bag so that no dust from the cage enters the lab spaces.

People at Sanford Lab
Profile Card

THERE AND BACK AGAIN

Bring your computer case, too! There is internet available underground, so that scientists and other workers can stay connected with the surface.

People at Sanford Lab
Profile Card

SANFORD LAB FAST FACT

4850 feet = 1, 478 kilometers = 0.92 miles

Scientists journey nearly one mile underground to the the Sanford Lab

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SANFORD LAB FAST FACT

800,000 tons = 725,747,792 kilograms

A lot of rock will be excavated for the new Deep Underground Neutrino Experiment.

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SANFORD LAB FAST FACT

20,000 pounds = 9,072 kilograms

The new LZ dark matter detector will use 10 tons of liquid xenon, Xe.

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SANFORD LAB FAST FACT

108,100 pounds = 49,033 kilograms

The MAJORANA Demonstrator uses 54 tons of lead bricks for shielding.

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THERE AND BACK AGAIN

The MAJORANA DEMONSTRATOR is located in a 'clean room'. People work to keep this space ultra clean, because even a single fingerprint could ruin the experiment. Before entering this lab, special clean-room clothing is required.

People at Sanford Lab Profile Card

THERE AND BACK AGAIN

The underground lab is for students and teachers, too! This education specialist might go underground to use technology to connect students with scientists. She needs to bring her computer--and be sure to wear all the required safety equipment.

People at Sanford Lab Profile Card

THERE AND BACK AGAIN

Safety Equipment Required!

- safety belt with a respirator
- a hardhat
- head-lamp and a battery pack
- steel-toed boots
- safety glasses
- reflective coveralls

People at Sanford Lab Profile Card

THERE AND BACK AGAIN

The Sanford Lab welcomes college and graduate students from many institutions. Everyone who works or visits underground must be at least 18 years old.

People at Sanford Lab Profile Card

SANFORD LAB FAST FACT

Thousands of students and teachers from South Dakota connect with the Sanford Lab every year--for field trips, presentations and curriculum units.

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SANFORD LAB FAST FACT

0.93 cm = 0.37 inches

The MAJORANA DEMONSTRATOR uses pure copper which grows underground at a rate of only 0.93 cm *per year*.

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SANFORD LAB FAST FACT

10,000 pounds = 4536 kilograms

The capacity of the cage is 10,000 pounds. The average adult person weighs 150 pounds. Does the **weight** capacity limit the number of people who can ride in the cage?

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SANFORD LAB FAST FACT

Safety is a core value at Sanford Lab. Everyone who travels to the underground lab pays close attention to safety procedures.

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You decide!

SANFORD LAB
FAST FACT

370 miles = 595 kilometers

There are hundreds of miles of tunnels, carved by the Homestake Mining Company as they searched for gold.

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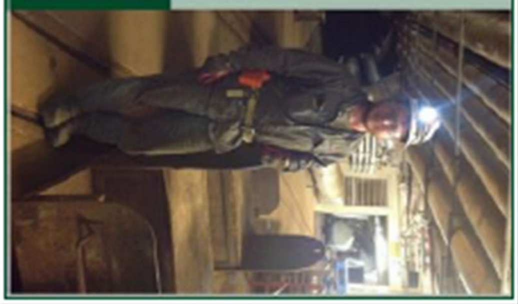
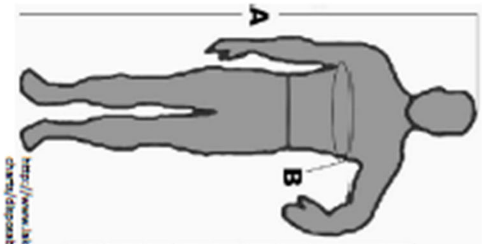
THERE AND BACK AGAIN

Everyone who goes to the underground lab wears a hard hat with a head-lamp and orange battery pack. Some areas of the underground would be totally dark without your headlamp for light!



People at Sanford Lab
Profile Card

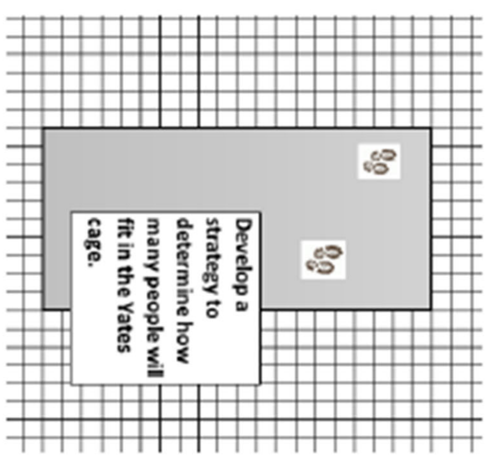


Body Dimensions

	A	B
Garment Size	Body Height cm	Chest Girth cm
S	164 - 170	84 - 92
M	170 - 176	92 - 100
L	176 - 182	100 - 108
XL	182 - 188	108 - 116
2XL	188 - 194	116 - 124
3XL	194 - 200	124 - 132

Note that these sizes relate to the BODY SIZE of the wearer and are not actual garment dimensions

http://www.lakeland.com/asiapacific/our-products/technical-information/size-charts/disposable-clothing-size-charts.html



Muck Boot Sizing Chart

BOOT SIZE	LENGTH (CM)
MEN'S 5/WOMEN'S 6	23.5
MEN'S 6/WOMEN'S 7	24.2
MEN'S 7/WOMEN'S 8	25
MEN'S 8/WOMEN'S 9	26
MEN'S 9/WOMEN'S 10	27
MEN'S 10/WOMEN'S 11	28
MEN'S 11/WOMEN'S 12	28.9
MEN'S 12/WOMEN'S 13	30
MEN'S 13	30.7
MEN'S 14	31.3
MEN'S 15	32.5
MEN'S 16	33.1

Note: the above measurements are guidelines only

There and Back Again Refurbishment Inventory

Lesson	*Quantity*	*Item*	
All	1	Facilitator Binder w/ USB	
	1	Shipping Tote	
Lesson 1	8	Blue Painters Tape (Rolls)	
	16	Unit Cube (cm)	
Lesson 2	8	Set of Scientist Profile Cards	
Lesson 3	15	Hoist Diagram	
	30	Centimeter Grid Paper	
	15	6" Centimeter Rulers	
	1	Roll Duct Tape	
	15	Set of 6 Bolts	
Lesson 4	15-30	Model Cage from Lesson 3	
	15	Lesson 4 Building Kit	
		Pulley	String
		J-Hook	C-Clamp
		Bowl	Long Dowel
		Measuring Tape	
	15	Set of 6 Bolts	
	1	Roll of String	
	90	Bolts	
Lesson 5	15-30	Model Cage from Lesson 3	
	15	Building Kit	
		Spool	Clothespins (2)
		Clip (2)	Rubber bands (2)
		Short Dowel	
	15	Lesson 4 Building Kit	
	1	Package Rubber Bands	
	15	Motor	
	15	D-Cell Battery	
	15	Set of 6 Bolts	

NOTICE: THE HEADER/FOOTER AND REVISION HISTORY OF THIS ATTACHMENT IS NOT INCLUDED IN THE PRINTED DELIVERABLE.ANY BLANK PAGES ARE LEFT SO INTENTIONALLY.

Revision History

Rev	Date	Section	Paragraph	Summary of Change	Authorized by
01	2/27/2024	NA	NA	Initial Release	CCR 911