

Physics of the Tractor Pull Curriculum



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About the Author



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After teaching high school math and science for eight years in Virginia and Minnesota, he began teaching at Minnesota State University Moorhead, where he is now a full professor and Chair of the Department of Chemistry and Biochemistry. He helps his daughters raise and show sheep in his spare time, and enjoys travelling extensively during the summer.

Alignments

Alignment With Next Generation Science Standards

This curriculum partially fulfills HS-PS2-1: Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

These lessons are well aligned with MS-PS2-2: Plan an investigation* to provide evidence that the change in an objects's motion depends on the sum of the forces on the object and the mass of the object.

* In order to meet this portion of the standard, the participants would at least need to be involved in co-designing the investigation; the procedure could not be handed to them with no input on their part.

The tractor pull is an excellent phenomenon through which to study Isaac Newton's first three Laws of Motion. The sled used in the tractor pull is an engineering marvel designed to gradually increase resistance which allows varying endpoints based on the strength of the pull. Rural participants in particular may have seen tractor pulls, or even participated firsthand in pedal (tractor) pulls at local fairs and/or community events. Regardless, the tractor and sled system provides an interesting context that can be explored simply (with middle school math) or at a much more mathematically sophisticated level.

Curriculum Structure

The *Physics of the Tractor Pull Curriculum* is composed of the following lessons. Approximate lesson times are included.

Lesson	Title	Approximate Time
One	About the Tractor	60 minutes
Two	Divide and Conquer!	60 minutes
Three	Analyze the Data	60 minutes
Four	Science Behind the Tractor	60 minutes
Five	Tractor Pull	60 minutes
	Total	5 hours

Lesson Structure

Each lesson begins with a Lesson Overview, Lesson Objectives, and a Lesson at a Glance table that lists lesson activities, materials required, suggested preparation steps, and approximate class time.

Lesson Sections

The actual lesson follows the overview, which contains some of the sections described below.

FOCUS

Every lesson begins with a FOCUS activity intended to capture participants' attention. This may be in the form of a small or large class discussion, a game, a demonstration, or a review of previous lesson information. During this activity, participants are introduced to the topic of the lesson.

LEARN

The LEARN activity in each lesson varies in its presentation mode. It may be a slide presentation, group activity, or demonstration.

REVIEW

The majority of lessons end with a REVIEW activity intended to briefly review the lesson's key messages or main points.

Lesson One – About the Tractor

Lesson Overview

In this lesson, participants will examine how to modify the tractor. In addition, participants will talk about how to create a series of tests that will give the best information on what changes make the most impact.

Lesson Objectives

After completing this lesson, participants will be able to:

- Describe the parts of the tractor and know how to modify them
- Describe what makes a scientific test “fair”

Lesson at a Glance

Activity	Materials	Preparation	Approximate class time
FOCUS	1. <i>Brainstorming</i> worksheet (optional) 2. <i>Brainstorming</i> worksheet – Answer Key (optional) 3. Video of tractor pulls: https://www.youtube.com/watch?v=HKfpcyxOALc or https://www.youtube.com/watch?v=SIAMZzGnMKc This one is particularly nice. It very clearly shows the key features such as the weight moving up, causing the tractor to go slower and slower. Only the first 80 seconds are necessary.	1. Prepare video clips for viewing. 2. Print/photocopy <i>Brainstorming</i> (optional, one per participant)	10 minutes
LEARN	1. <i>About the Tractor</i> slide presentation 2. <i>Getting To Know Your Tractor</i> worksheet 3. <i>Getting To Know Your Tractor</i> worksheet – Answer Key 4. Metric rulers and protractors (one per group, optional) 5. RC tractors (one per group)	1. Print/photocopy <i>Getting To Know Your Tractor</i> (one per participant). 2. Prepare the <i>About the Tractor</i> slide presentation for viewing.	45 minutes
REVIEW	1. <i>Lesson One Quiz</i> 2. <i>Lesson One Quiz</i> – Answer Key	1. Print/photocopy <i>Lesson One Quiz</i> (one per participant).	5 minutes

Lesson One – About the Tractor

FOCUS: Tractor Pull Videos

10 minutes

Purpose:

Participants will watch the videos of a tractor pull or a pedal pull to understand the phenomenon. They will see that the tractor eventually stops. Brainstorm in class why this is so; the purpose of the rest of this lesson, and the broader series of lessons, is to determine exactly where a tractor/sled combination will stop.

Materials:

1. Videos of tractor pull events
 - Child's pedal-powered tractor pull (90 seconds):
<https://www.youtube.com/watch?v=HKfpcyxOALc>
 - Actual tractor pull (10 minutes, but first 80 seconds is all that is necessary):
<https://www.youtube.com/watch?v=S1AMZzGnMKc>
2. Copies of *Brainstorming* worksheet (optional)

Facilitation Steps:

1. Distribute the *Brainstorming* worksheet to participants (optional).
2. Ask participants if they have ever seen, or even been part of, a tractor pull.
3. Show 'Child's pedal-powered tractor pull' video.
4. Show 'Actual tractor pull' videos.
5. Facilitate a brainstorming discussion using the *Brainstorming* worksheet. You or the participants can write down ideas. There are no right or wrong answers at this point.
6. Ask participants, "Why did the tractors come to a stop?"
7. Ask participants, 'Did you notice anything changing about the sled?'
8. Discuss similarities and differences between the real tractor pull and the pedal pull.

Name: _____ Class: _____

Brainstorming

Directions: After reviewing the tractor pull videos, answer the following questions.

1. Why does the tractor come to a stop?
2. Did you notice anything happening with the trailer (we will call this a sled) as it was pulled?
3. Did you notice any similarities between the real tractor pull and the kid's pedal pull?
4. Is there anything you can add from personal experience with a tractor pull of any kind?

Brainstorming – Answer Key

(There are no right or wrong answers at this point, just brainstorming possibilities)

Directions: After reviewing the tractor pull videos, answer the following questions.

1. Why does the tractor come to a stop?

Answers will vary – the kid got tired, the tractor ran out of fuel, etc. The actual answer is that the sled gets harder to pull, because the weight (we will call this the weight box on our model) moves from the back of the sled, over the wheels, to the front of the sled, over the skid plate where there is more friction.

2. Did you notice anything happening with the trailer (we will call this a sled) as it was pulled?

Hopefully at least a few participants will notice that the weight box moves from the back of the sled to the skid plate. If no one notices this, perhaps reshow the video and ask them to watch carefully.

3. Did you notice any similarities between the real tractor pull and the kid pedal pull?

Both have the same moving weight on the sled. Both come to a stop eventually (usually).

4. Is there anything you can add from personal experience with a tractor pull of any kind?

Answers will vary.

Lesson One – About the Tractor

LEARN: Understanding the Tractor/Sled System

45 minutes

Purpose:

Participants will learn and understand that the tractor/sled system is made up of several parts.

- Understand how to change the parts of the tractor
- Understand how the sled works, particularly friction
- Understand the overall reason why the sled stops (unbalanced forces as per Newton's 1st law)

Materials:

- *About the Tractor* slide presentation
- Tractors
- Metric ruler and protractor (optional)
- *Getting To Know Your Tractor* worksheet
- *Getting To Know Your Tractor* worksheet – Answer Key

Facilitation Steps:

1. Organize groups of 3-4 participants. Groups should be set for days one through four. Switching groups for day five makes it more likely that tricks learned in one group will spread across the class, resulting in a fairer competition. Keeping the same groups on day five should result in more efficiency since they are already familiar with their roles.

On days one through four, homogeneous groups make more sense. Some variables are more complex; the hitch can be explored on many levels, up through differential equations (calculus). Other variables, such as changing the gears or wheels, have limited options and are easier to analyze.

If an accommodation (Spanish translation) is needed, a homogenous group of ESL learners could all get the same handout.

For day five however, groups should be as fair as possible with each group having a

similar mix of academic achievers and those with good mechanical skills.

2. Go over the *About the Tractor* slide presentation with participants.

Slide 1: Title slide

Slide 2: Curriculum overview

Slide 3: Overview of Newton's Laws

Optional notes on Isaac Newton's background:

Isaac Newton is usually regarded as the most influential scientists (and Michael Hart ranks him as the second most influential person in his book *The 100: A ranking of the Most Influential Persons in History*) of all time. He advanced knowledge in and created entire categories of science (optics, acoustics, kinematics, fluid dynamics) as well as a whole new mathematics category (calculus) to understand these new physics problems.

Perhaps one of his greatest accomplishments is moving the study of science forward as a whole with the tenet that the laws of science are universal; i.e., the forces and rules that govern the motion of the planets are the same forces and rules that govern the motion of objects on Earth, such as an apple falling to the ground.

The story is that Newton was contemplating the motion of the planets in the heavens when an apple fell on his head. He put two and two together about the universal nature of science through his Law of Universal Gravitation.

Slide 4: Newton's 1st Law

Optional notes on this law:

Think about it for a second. When you throw or kick a ball, does it come to a stop or stay in motion? It comes to a stop every time. So, if you think about it, this is an odd way to phrase things, with the "normal" behavior (it comes to a stop) as the exception ("unless"). Why?

This is tied back to the universal nature of scientific laws, because this ALSO must cover the motion of planets. Earth has orbited the sun for almost five billion years; i.e., Earth is in motion, and it has stayed in motion for almost five billion years. That must be the natural state. It's just that on Earth, we always run into external forces like friction.

Slide 5: Net External Force

Many times, the word “net” is left out of this definition, but leaving it out can cause misconceptions. There are forces at the start, the pull of the tractor and friction from the sled, but the net force at the start is forward since $F_{\text{tractor}} > F_{\text{friction}}$.

These same two forces are still at work when the tractor slows to a stop, but now friction of the tractor is less than the friction of the sled. So, to just say “until acted upon by a force” ... well the same two forces are there all the time. It's just that the net ($F_{\text{tractor}} - F_{\text{friction}}$) goes from a positive number (starting from rest and speeding up) to a negative number (slowing to a stop).

Slide 6: Force Diagram

The Force Diagram is also called a Free Body Diagram.

The asterisk is by “all” because sometimes we leave out forces that are not of concern... like on the next slide where gravity and normal force are left out because they're equal and opposite, canceling each other out.

Slide 7: Force Diagram of Sled: Start

We will leave out the forces of gravity and something called the Normal Force (or surface force) for now. If participants mention these forces, they're not wrong (these forces are present) but it's true that the forces in one direction (side to side) are independent of the forces in another direction (up and down).

We also use the convention that the directions of the arrows correspond to the Cartesian Coordinates (i.e., X and Y axis with up being the + Y, down being the -Y, right being + X, and left being -X).

Since the right-pointing arrow is longer than the left-pointing arrow, the sled moves right.

Slide 8: Why Does the Sled Stop? Two Possible Hypotheses

One of two options must be the reason. In science, we collect data to determine which option is supported by evidence. This data is provided.

Slide 9: Pull of the Tractor Over Time

Participants will notice that while there is some variability (20s has a higher force than 15s and 25s to 50s stay constant at 4.8N) the overall trend is a slight decrease in the force output by the tractor. However, this trend is very small, less than 20%, and much less than the 250% change in force that we will see on the next slide when varying the distance moved by the sled. Very often in the real world, there are some data that make a conclusion slightly less clear.

Both hypotheses are supported to some extent, but one is MUCH more strongly supported. No matter the amount of weight used, each graph on the next page shows a nice, straight line that increases as the distance increases. The increase is substantial (at least 150%).

Slide 10: Force Required To Pull the Sled at Various Distances

As can be seen here, the force needed to pull the sled at various distances increases as the distance increases.

Slide 11: Based on the Evidence, Why Does the Tractor Stop?

While the pull from the tractor remains virtually constant, the friction from the sled increases. When the friction from the sled gets bigger than the pull of the tractor, the tractor will have a change in NET force (net force goes from being + to -) and the tractor will slow down and stop. If you collected your own data for the graphs on slides 9 and 10, you could theoretically solve for exactly how far it would go before this change happened, taking the equation for the force required to pull the sled from slide 10 ($y = 0.4643X + 3.9833$), setting it equal to the force that the tractor pulls with (5N, from slide 9), and solving for X (the distance where these two forces become equal).

Slide 12: Parts of the Model: Sled

Be careful when resetting the sled after each trial. The sled is somewhat fragile and can be damaged if participants try to carry the sled with too much weight in the sled.

Be sure to reset the weight box to the bottom of the rails and to make sure that the string starts the same (i.e., no slack).

Slide 13: How Does the Sled Change Its Resistance (no notes)

Slide 14: How Does the Sled Change Its Resistance

Participants can find this relationship if the force needed to lift the front of the sled is measured at several distances as the sled moves forward, the force needed to pull the sled at that distance is measured at the same distance, and these numbers are graphed (force to pull vs. force to lift). The relationship will be the coefficient of friction for the sled's skid plate.

Slide 15: What Is Friction?

Static friction is when the two surfaces don't slide. For example, you plant your foot and push off to start running. If your foot doesn't slide, that's static friction.

Kinetic friction is when two surfaces slide. For example, you push a box across the floor. The bottom of the box has kinetic friction with the floor.

Kinetic friction is generally smaller than static. It's good if you are trying to move something, but bad if you are trying to get a grip yourself. This is a problem when you're driving and your brakes lock up (and why anti-lock brakes were invented). You don't want your brakes to lock and your wheels to slide because then you lose control because you have no traction (i.e., friction). Anti-lock brakes attempt to prevent the slide and keep the stronger static friction (rolling friction) in place, giving you more control over your vehicle.

Slide 16: Parts of the model: Tractor

It might be useful at this point for participants to have a tractor in their hands.

The remaining pictures will show the tractor with the cover removed.

Wipe the wheels with rubbing alcohol between each run on day two. For day five, all bets are off and participants should decide whether they wipe or don't wipe their wheels. Some may even find that having the wheels slightly wet increases their advantage (just as basketball and volleyball teams will often have a slightly wet towel that substitutions wipe their feet on just before entering the game, or during a timeout).

Slide 17: Charging Tractor, Cover Removed (no notes)

Slide 18: Location of Set Screws

Slide 19: Tires

The tiny washer on the rear tire bolts sometimes stays on the bolt, and sometimes stays in the wheel hub. They are easy to lose. Keep a baggie and possibly a magnet with each set – the bolts and washers will all stick to a magnet.

Slide 20: Gears

The gears, particularly the large spur gears, require:

1. Alignment of the flat spot on the gear with the flat spot on the axle.
2. Some force applied (especially the first few times) to slide the gears on and off.
3. A delicate touch as it's easy to snap the gear in half if too much force is applied without some care.

Also, encourage your participants not to fully remove the set screws on the gears and collars as they are tiny and easily lost.

Slide 21: Posts for Weights

Image focuses on the posts for the weights. The posts only hold about 20 weights each; it's not possible to put all 60 in the middle (or in the front) and still secure them with the nut.

Slide 22: Adjusting the Hitch Height

Image showing how to adjust the hitch height using included wrench. The hitch height is the single most important variable (because it changes friction). When the hitch is in the highest position, it changes two important variables in this system.

1. It causes the weight of the sled to pull down on the rear of the tractor, increasing

the amount of traction possible and greatly enhancing the tractor's pulling ability.

2. It causes less weight to rest on the skid plate of the sled, greatly reducing the amount of friction at that point and making it easier for the tractor to pull.

If the hitch is given a $\frac{1}{2}$ turn, so that it's horizontal, the angle that the connecting rope makes with the hitch is a little steeper (the bottom of the hitch is just a little higher) and that might be the deciding factor on day five. But for day two, finding the patterns, it's essential that participants only change one variable at a time, so leave the hitch vertical.

Slide 23: Getting to Know Your Tractor

Distribute the *Getting To Know Your Tractor* worksheet, one per participant. Give participants time to complete this quick activity before finishing the slide presentation.

A 9-cm string is about 3.5 inches.

The angles should be less than 30° .

Slide 24: Procedure: What makes a Fair Test?

The Next Generation Science Standards require participants to be active agents in developing a procedure. While a procedure has been provided, it is encouraged that teachers use the guidelines on this slide to at least brainstorm the procedure with the class before sharing the procedure handout (Day 2), if not letting the participants develop their own procedures without being handed a cookbook procedure in true inquiry fashion.

- Try to keep everything (control variables) the same except the variable that you change (independent variable) and the variable you're measuring (dependent variable). This includes wiping the tires, sweeping the floor, etc. between runs.
 - One control variable would be the angle of the pull, since pulling up at an angle would reduce friction.
- Observations should also be recorded. One of the most important is if the wheels spin out.

- Carefully record data in a table. I don't like to provide a table to my participants because if they don't practice setting it up themselves, they will never learn. However, it's easier to provide that table. Creating it together is a good compromise.

- Data should be collected over a reasonable range. The range should be as large as reasonable, and the points should be taken over several evenly spaced values across the range. In some cases, the materials provide the limits (i.e., there are only two pinion and three spur gears included as well as only two different wheels). In other cases, there are virtually an infinite number of possibilities (hitch heights and weight distributions). In this case, it makes sense to test some extreme cases (max weight front, max weight middle, even distribution, no weights, max hitch up, max hitch down, hitch in the middle). Testing settings too close to each other (19 washers on each middle post and five washers on each front post vs. 20 washers on each middle post and four washers on each front post) is not time effective.

Slide 25: Sample Table for Day 2

Ideally, you would help each of the five groups to think through changing one variable at a time.

Weights have the most configuration to try, and other groups can help with this.

Group 1: Row 2 differs from row 1 in that they changed only the tire size (large and small).

Group 2: Row 3 differs from row 1 in that they changed only the pinion gear (large and small).

Group 3: Rows 4-5 differ from row 1 in that they changed only the spur gear size (small, medium, and large).

Group 4: Row 6-7 differ from row 1 in that they changed only the height of the hitch (low, medium, and high).

Group 5: Row 8-? differ from row 1 in that they changed only the distribution of the weights (there

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are several configurations here: max middle, max front, even, none). Repeat as needed.

3. Participants should prepare for day 2.
 - a. Use the same groups.
 - b. Set up the tractor for the first run, if possible.
 - c. Have a copy of the data table.
4. Data can be recorded in a table in a lab notebook and/or directly in a shared spreadsheet program such as Microsoft Excel or Google Sheets.

Name: _____ Class: _____

Getting To Know Your Tractor

Purpose: In order to calculate the theoretical force that the tractor can apply, it's important that you have certain measurements. You will use these measurements on Days 3 and 4.

Directions:

Record all of the following in the table below:

- The diameter of each of the 3 spur gears to the nearest millimeter.
- The diameter of each of the 2 tires to the nearest millimeter.
- The number of teeth on each of the 3 spur gears.
- The number of teeth on each of the 2 pinion gears.
- (Optional) attach a 9-cm string to the the hitch. Holding the other end on the ground, measure the angle that the string makes with the ground when the hitch is in 3 different positions, including the highest and lowest possible positions.

Data table 1:

	Diameter (mm)	Teeth
Large spur gear		
Medium spur gear		
Small spur gear		
Large wheel		
Small wheel		
Large pinon gear		
Small pinion gear		

Data table 2:

Hitch position	Angle string makes with floor
Highest position	
Middle position	
Lowest position	

Name: _____ Class: _____

Getting To Know Your Tractor – Answer Key

Purpose: In order to calculate the theoretical force that the tractor can apply, it's important that you have certain measurements. You will use these measurements in Days 3 and 4.

Directions:

Record all of the following in the table below:

- The diameter of each of the 3 spur gears to the nearest millimeter.
- The diameter of each of the 2 tires to the nearest millimeter.
- The number of teeth on each of the 3 spur gears.
- The number of teeth on each of the 2 pinion gears.
- (Optional) attach a 9-cm string to the the hitch. Holding the other end on the ground, measure the angle that the string makes with the ground when the hitch is in 3 different positions, including the highest and lowest possible positions.

Data table 1:

	Diameter (mm)	Teeth
Large driven gear	62.5	60
Medium spur gear	57.5	55
Small spur gear	50	50
Large wheel	72.5	
Small wheel	62.5	
Large pinion gear		12
Small pinion gear		10

Data table 2:

Hitch position	Angle string makes with floor
Highest position	15°
Middle position	10°
Lowest position	3°

Lesson One – About the Tractor

REVIEW: Exit Quiz

5 minutes

Purpose:

Participants review the key concepts from this lesson and take an exit quiz.

Materials:

- *Lesson One Quiz*
- *Lesson One Quiz – Answer Key*

Facilitation Steps:

1. Distribute the quizzes to participants and give them five minutes to complete it.

Name: _____ Class: _____

Lesson One Quiz

Directions: Answer the following questions.

1. How many variables should you change at 1 time in a fair experiment?
2. True/False The sum of all the forces on an object is the net force.
3. True/False An internal force can cause an object to change its motion.
4. Why does the sled come to a stop?
 - a. When the pull of the tractor increases above the resistance of the sled
 - b. When the resistance of the sled increases above the pull of the tractor
 - c. When the pull of the tractor and the resistance of the sled are equal
5. When adjusting the spur gear, what other part of the tractor must be adjusted?
 - a. The tires
 - b. The weights
 - c. The motor
 - d. The hitch
6. If testing the effect of changing the hitch height, which other variables should be kept the same?
 - a. The weight distribution
 - b. The size of the tires
 - c. The spur gear size
 - d. All of the above
7. What increases the friction of an object?
 - a. Increased weight
 - b. Smoother surfaces
 - c. All of the above

Lesson One Quiz – Answer Key

Directions: Answer the following questions.

1. How many variables should you change at 1 time in a fair experiment? **ONE**
2. **True/False** The sum of all the forces on an object is the net force.
3. True/**False** An internal force can cause an object to change its motion.
4. Why does the sled come to a stop?
 - a. When the pull of the tractor increases above the resistance of the sled
 - b. When the resistance of the sled increases above the pull of the tractor**
 - c. When the pull of the tractor and the resistance of the sled are equal
5. When adjusting the spur gear, what other part of the tractor must be adjusted?
 - a. The tires
 - b. The weights
 - c. The motor**
 - d. The hitch
6. If testing the effect of changing the hitch height, which other variables should be kept the same?
 - a. The weight distribution
 - b. The size of the tires
 - c. The spur gear size
 - d. All of the above**
7. What increases the friction of an object?
 - a. More weight**
 - b. Smoother surfaces
 - c. All of the above

Lesson Two – Divide and Conquer!

Lesson Overview

In lesson two, participants will collect data on various configurations of the tractor to analyze over days three and four.

Lesson Objectives

After completing this lesson, participants will be able to:

- Design and conduct a fair test to measure the effect of one variable on another
- Determine appropriate sampling for continuous independent variables
- Keep control variable constant
- Accurately measure distance

Lesson at a Glance

Activity	Materials	Preparation	Approximate class time
FOCUS	1. <i>Divide and Conquer!</i> slide presentation	1. Prepare the <i>Divide and Conquer!</i> slide presentation for viewing.	10 minutes
LEARN	1. <i>Divide and Conquer!</i> slide presentation (slides 1-7) 2. Tractor kit (one per group) 3. Tape to mark out the track 4. Tape measure 5. Sled with 8 lbs of weights in the weight box 6. Computer with Google Sheets or other collaborative spreadsheet such as Excel with Sharepoint (one per group, optional) 7. <i>Divide and Conquer!</i> – Data Table 8. <i>Divide and Conquer!</i> – Answer Key	1. Mark the boundaries of the course, the start, and finish line as indicated. 2. Test your particular floor conditions. You need sufficient weight in the weight box that no configuration with the hitch in the down position can achieve a full pull. 3. Copy/print <i>Divide and Conquer!</i> – Data Table	35 minutes
REVIEW	1. <i>Divide and Conquer!</i> slide presentation (slides 8-16) 2. <i>C.E.R. Framework</i> worksheet (one per participant) 3. <i>C.E.R. Framework</i> – Answer Key 4. <i>C.E.R. Framework Summary</i> for each group 5. <i>C.E.R. Framework Summary</i> – Answer Key	1. Copy/print <i>C.E.R. Framework</i> worksheets (one per participant) There are five different <i>C.E.R. Framework</i> documents, one for each variable/group. Example: You have five groups with four participants in each group. You would make four copies of <i>C.E.R. Framework 1</i> for group 1, four copies of <i>C.E.R. Framework 2</i> for group 2, etc. 2. <i>C.E.R. Framework Summary</i> worksheet (one per group)	15 minutes

Lesson Two – Divide and Conquer!

FOCUS: What Makes a Fair Test?

10 minutes

Purpose:

Instructor leads participants in a class discussion to review the plan for the day. The goal is to collect as much data as possible regarding the effect of changing one variable at a time on the tractor.

Materials:

- *Divide and Conquer!* slide presentation (slides 1-7)

Facilitation Steps:

1. Show slides one through seven of the *Divide and Conquer!* slide presentation.

Slide 1: Title slide

Slide 2: Goal

Having a data table where everyone can enter their data at the same time is ideal. For example, a shared spreadsheet in Google Sheets, Excel in a shared Sharepoint document, etc.

Slide 3: What makes a fair test?

Make sure participants understand that there are variables you change (*independent*), variables you don't (*control*), and variables that change as a result (*dependent*). The Next Generation Science Standards require participants to be active agents in developing a procedure. While a procedure is provided, it's encouraged that teachers use the guidelines in this slide to at least brainstorm the procedure with the class before sharing the procedure handout, if not letting the participants develop their own procedures without being handed a cookbook procedure in true inquiry fashion.

- Try to keep everything (*control variables*) the same except the variable that you're changing (*independent variable*) and the variable you're measuring (*dependent variable*). This includes wiping the tires, sweeping the floor, etc. between runs.
- Observations should also be recorded. One of the most important is whether the wheels spin out.
- Carefully record data in a table.

- Data should be collected over a reasonable range. The range should be as large as reasonable, and the points should be taken over several evenly spaced values across the range. In some cases, the materials provide the limits (i.e., there are only two pinion and three spur gears included and only two different tires). In other cases, though, there are virtually an infinite number of possibilities (hitch heights and weight distributions). In this case, it makes sense to test some extreme cases (max weight front, max weight middle, even distribution, no weights, max hitch up, max hitch down, hitch in the middle). Testing settings too close to each other (19 weights on each middle post and five weights on each front post vs. 20 weights on each middle post and four weights on each front post) is not time effective.

Slide 4: Procedure (no notes)

Slide 5: Make Changes, Wait Your Turn

This is a complicated system. The changes to the gears and tires will have a surprisingly small impact on the pull compared to changes in the hitch and weight distribution. In fact, the effects of these changes could be lost in the measurement error, so be extra careful when measuring these adjustments.

Slide 6: Sample Table

Helping each of the five groups think through changing one variable at a time would be most beneficial.

Note: Each group does not need to retest row 1; these configurations are bolded and underlined in the slide. You don't retest them as there is not time. If there was time, this would provide a good control; do the different tractors get the same result with the same setup?

Group 1: Row 2 differs from row 1 in that they changed only the tire size (large and small).

Group 2: Row 3 differs from row 1 in that they changed only the pinion gear (small vs. large).

Physics of the Tractor Pull Curriculum

Group 3: Rows 4-5 differ from row 1 in that they changed only the spur gear size (small, medium, and large).

Group 4: Rows 6-7 differ from row 1 in that they changed only the height of the hitch (low, medium, and high).

Slide 7: Sample Table

Weights have the most configurations to try, and other groups can help with this or move on to rows 4-7.

Group 5: Rows 1-3 on this sheet differ from row 1 on the previous sheet in that they changed only the distribution of the weights (there are several configurations here: max middle, max front, *even*, none).

Row 4: Because the hitch height is so important, start over with the hitch height “high” if time remains. This row is the same as row 7 in the previous slide, except we now have the tires changed to small.

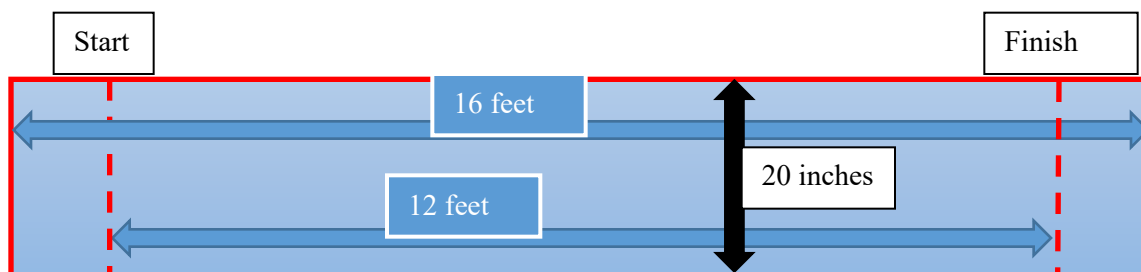
Rows 4-7: Here we are going back, and the bold/underlined word is what changed since row 7 on the previous slide.

If time allows, this pattern could be continued with three more trials (front max, middle max, none).

With the hitch in the high position, there might be far less spinning out observed.

Lesson Two – Divide and Conquer!

LEARN: Testing Tractor Configurations



35 minutes

Purpose:

Participants test each of the variables one at a time, pinion gear, spur gear, tires, hitch height, and weight distribution to see what effect each has in isolation.

Materials:

- Sled and sled weights
- Track marked on a large, open space with a smooth floor
- Tractor kits (one per group)
- Computer with Excel and Sharepoint or Google Sheets (one per group, optional)
- *Divide and Conquer!* slide presentation (slides six and seven)
- *Divide and Conquer!* - Data Table (one per participant).
- *Divide and Conquer!* - Data Table – Answer Key

Facilitation Steps:

1. Make sure by this point the competition space is marked as indicated above with at least 16 feet in length, 20 inches in width, a finish line approximately 12 feet from the starting line, and a foot of space before the start line and after the finish line.
2. Break participants into groups. See lesson one notes on groups.
3. Distribute the *Divide and Conquer!* – Data Table to each participant.
4. Allow the participants to carry out the lab, recording the data on the appropriate sheets or in Excel/Sheets, if these are available to participants in your setting.
5. Each group should now take their tractor and modify it according to their group variable.
6. While these are listed in order on the data sheet, it's NOT necessary for them to be tested in the same order. The goal here is to collect as much data as accurately as possible. It will take time to switch a tractor over from one setting to another. If the group on the next row of the data table is not ready, don't wait for them. Take the group for the next row that is ready, but make sure to clearly identify which setup this is. Once the previous group is ready, then rotate them back in.
7. After each run, the data should be recorded, either on the board or a shared document.
8. Group 2 should go first, completing the 1st row of data (large, small, small, low, even).
9. Group 1 should be ready and go next for the 2nd row (SMALL, small, small, low, even).
10. Group 2 should have prepared their tractor for the 3rd row while Group 1 went, and be ready to test the third row.
11. Group 3 should have prepared their tractor for the 4th row. Etc.
12. When a group has multiple changes in a row (Group 5 with front max weight, middle max, and none), this will take time. Make sure groups 1-3 are set to then do the remaining tests on Slide 7.
13. If time allows, additional data could be collected using:
 - Large tires, small pinion gear, small spur gear, high hitch, and the same weight variation from the first 3 rows of slide 7 (front max, middle max, and none).

Physics of the Tractor Pull Curriculum

Slide 6: Sample Table

Record the data from the first seven runs.

Slide 7: Sample Table

Record the data from the next seven runs.

14. Make sure to leave five minutes for cleanup
and at least 15 minutes for review.

Name: _____ Class: _____

Divide and Conquer – Data Table

Directions: Place your data from all experiments in the table below.

Tires	Pinion Gear	Spur Gear	Hitch	Weights	Pull (m) and comments
Large	Small	Small	Low	Even	
<u>Small</u> ¹	Small	Small	Low	Even	
Large	<u>Large</u> ²	Small	Low	Even	
Large	Small	<u>Medium</u> ³	Low	Even	
Large	Small	<u>Large</u> ³	Low	Even	
Large	Small	Small	<u>Medium</u> ⁴	Even	
Large	Small	Small	<u>High</u> ⁴	Even	
Large	Small	Small	Low	<u>Front max</u> ⁵	
Large	Small	Small	Low	<u>Middle max</u> ⁵	
Large	Small	Small	Low	<u>None</u> ⁵	
<u>Small</u> ¹	Small	Small	High	Even	
Large	<u>Large</u> ²	Small	High	Even	
Large	Small	<u>Medium</u> ³	High	Even	
Large	Small	<u>Large</u> ³	High	Even	

Name: _____ Class: _____

Divide and Conquer – Answer Key

Directions: Place your data from all experiments in the table below.

Tires	Pinion Gear	Spur Gear	Hitch	Weights	Pull (m) and comments
Large	Small	Small	Low	Even	Most of these will pull less/spin out. The small tires, small pinion gears, and large spur gears work better.
<u>Small</u>¹	Small	Small	Low	Even	
Large	<u>Large</u>²	Small	Low	Even	
Large	Small	<u>Medium</u>³	Low	Even	
Large	Small	<u>Large</u>³	Low	Even	
Large	Small	Small	<u>Medium</u>⁴	Even	The higher the hitch, the better it pulls.
Large	Small	Small	<u>High</u>⁴	Even	
Large	Small	Small	Low	<u>Front max</u>⁵	The more weight, and the more weight in the back, the better it should pull.
Large	Small	Small	Low	<u>Middle max</u>⁵	
Large	Small	Small	Low	<u>None</u>⁵	
<u>Small</u>¹	Small	Small	High	Even	Most of these will pull better. The small tires, small pinion gears, and large spur gears work better.
Large	<u>Large</u>²	Small	High	Even	
Large	Small	<u>Medium</u>³	High	Even	
Large	Small	<u>Large</u>³	High	Even	

Lesson Two – Divide and Conquer!

REVIEW: Claim Evidence Reasoning

15 minutes

Purpose:

Participants share their Claim Evidence Reasoning (C.E.R.) sheets (one variable per group).

Materials:

- *Divide and Conquer!* slide presentation (slides 8-16)
- *C.E.R. Framework* worksheet (one per participant). There are different worksheets for each group.
- *C.E.R. Summary* worksheet (one per participant) could be copied onto the back of the *C.E.R. Framework* worksheets if desired.
- View this link to help with explaining gears (optional)
<https://www.omnicalculator.com/physics/gear-ratio>

Facilitation Steps:

1. Show slides 8-16 and explain the Claim Evidence Reasoning framework.

Slide 8: Analysis of the Data

If this were the data collected, then the large tires resulted in a further distance, and thus better pull than the small tires.

Since the small wheels were observed to have spun out and the big wheels were not, it appears that spinning out might be bad.

Slide 9: C.E.R. Framework (no notes)

Slide 10: C.E.R.

This slide, and the data in slide seven that it's built upon, is false. It makes no sense to provide the right answer before they start. The smaller tires should pull more effectively, because they have a better mechanical advantage. For maximum power, you want the fewest teeth on the pinion gear, the most teeth/biggest spur gear, and the smallest tires.

Slide 11: C.E.R. Group 1

Each pair should be considered separately. Line 1 vs. line 2 (only the tires different) and Line 3 vs. line 4 (only tires are different). The difference might be much more pronounced at high hitch.

The small wheels should pull better.

It's crucial they don't try to compare line 2 to line 3. Here the difference is the hitch height. That's for another group.

Slide 12: C.E.R. Group 2

Each pair should be considered separately. Line 1 vs. line 2 (only pinion gears are different) and line 3 vs. line 4 (only pinion gears are different). The difference might be much more pronounced at high hitch.

The small pinion gear should pull better than the large pinion gear.

It's crucial they don't try to compare line 2 to line 3. Here the difference is the hitch height. That's for another group.

Slide 13: C.E.R. Group 3

Each set should be considered separately. Lines 1 through 3 (only spur gears are different) and lines 4 through 6 (only spur gears are different). The difference might be much more pronounced at a high hitch.

Within each set, the largest spur gear should produce the best pull.

They should not compare anything from lines 1 through 3 to lines 4 through 6. That's the job of the group comparing hitch heights.

Slide 14: C.E.R. Group 4

The hitch at the highest point should produce the best pull.

Slide 15: C.E.R. Group 5

Maximizing weight as far back as possible (middle max) should produce the best results.

Slide 16: The top three conclusions may not be noticed unless the hitch is in the high position.

A bigger wheel should go faster, but a smaller wheel should pull harder (mechanical advantage/torque).

A pinion gear with more teeth should go faster, but fewer teeth should pull harder (mechanical advantage/torque);

<https://www.omnicalculator.com/physics/gear-ratio> is handy for talking about gears).

A spur gear with fewer teeth should go faster, but more teeth should pull harder (same reasoning as above).

The hitch in the high position should pull much harder. The angle:

- Increases the downward force on the rear of the tractor (increases traction)
- Creates an upwards force on the skid plate decreasing the friction there.
- With the weight distribution, the more weight toward the middle of the tractor should increase the pull because this downward force (gravity/weight) towards the drive tires increases traction.

Traction = friction, and friction is good when your drive tires are trying to get a grip.

2. Give the *C.E.R. Framework* worksheet to each participant. There are different sheets for each group, so make sure the right group gets the right sheets.
3. Give the *C.E.R. Summary* worksheet to each participant. It may be copied onto the back of the *C.E.R. Framework* worksheet to save paper.

4. Give each group five minutes to complete their analysis and *C.E.R. Framework* worksheet. If they can't provide reasoning at this point (or if it's incorrect) they will have an opportunity to fix it in lessons three and four.
5. Ask each group to present their *C.E.R. Framework* worksheet. The other groups should copy each conclusion into their *C.E.R. Summary* worksheet. This should take about five minutes.
6. Provide an opportunity for other groups to comment if appropriate (particularly if there is a mistake).
7. If there is a mistake in analysis or results that seem unexpected, point it out to the participants as something to think about in lessons three and four.
8. Provide a structure for data to be shared (Google documents/Sharepoint would be perfect, but writing on the board and allowing students to copy would be another option).
9. As participants will have an opportunity to modify their *C.E.R. Framework* and *C.E.R. Summary* worksheets in lessons three and four, it's important that these either remain in their possession until the end of the curriculum module or that they're collected and returned to participants the next day.

Name: _____ Class: _____

Claim Evidence Reasoning (C.E.R.) Framework: Group 1

Directions: Complete the data table as well as the claim, evidence, and reasoning below.

Tires	Pinion Gear	Spur Gear	Hitch	Weights	Pull (m) and comments
<u>Large</u>	Small	Small	Low	Even	
<u>Small</u>	Small	Small	Low	Even	
<u>Small</u>	Small	Small	High	Even	
<u>Large</u>	Small	Small	High	Even	

C:

E:

R:

Name: _____ Class: _____

Claim Evidence Reasoning (C.E.R.)

Framework: Group 2

Directions: Complete the data table as well as the claim, evidence, and reasoning below.

Tires	Pinion Gear	Spur Gear	Hitch	Weights	Pull (m) and comments
Large	<u>Small</u>	Small	Low	Even	
Large	<u>Large</u>	Small	Low	Even	
Large	<u>Large</u>	Small	High	Even	
Large	<u>Small</u>	Small	High	Even	

C:

E:

R:

Name: _____ Class: _____

Claim Evidence Reasoning (C.E.R.) Framework: Group 3

Directions: Complete the data table as well as the claim, evidence, and reasoning below.

Tires	Pinion Gear	Spur Gear	Hitch	Weights	Pull (m) and comments
Large	Small	<u>Small</u>	Low	Even	
Large	Small	<u>Medium</u>	Low	Even	
Large	Small	<u>Large</u>	Low	Even	
Large	Small	<u>Small</u>	High	Even	
Large	Small	<u>Medium</u>	High	Even	
Large	Small	<u>Large</u>	High	Even	

C:

E:

R:

Name: _____ Class: _____

Claim Evidence Reasoning (C.E.R.) Framework: Group 4

Directions: Complete the data table as well as the claim, evidence, and reasoning below.

Tires	Pinion Gear	Driven Gear	Hitch	Weights	Pull (m) and comments
Large	Small	Small	<u>Low</u>	Even	
Large	Small	Small	<u>Medium</u>	Even	
Large	Small	Small	<u>High</u>	Even	

C:

E:

R:

Name: _____ Class: _____

Claim Evidence Reasoning (C.E.R.) Framework: Group 5

Directions: Complete the data table as well as the claim, evidence, and reasoning below.

Tires	Pinion Gear	Spur Gear	Hitch	Weights	Pull (m) and comments
Large	Small	Small	Low	<u>Even</u>	
Large	Small	Small	Low	<u>Front max</u>	
Large	Small	Small	Low	<u>Middle max</u>	
Large	Small	Small	Low	<u>None</u>	

C:

E:

R:

Name: _____

Class: _____

Claim Evidence Reasoning (C.E.R.) Framework: Group 1 – Answer Key

Directions: Complete the data table as well as the claim, evidence, and reasoning below.

Tires	Pinion Gear	Spur Gear	Hitch	Weights	Pull (m) and comments
<u>Large</u>	Small	Small	Low	Even	<u>Exact distances will vary, but the large tires should pull less than the small tires.</u>
<u>Small</u>	Small	Small	Low	Even	
<u>Small</u>	Small	Small	High	Even	<u>Exact distances will vary, but the large tires should pull less than the small tires.</u>
<u>Large</u>	Small	Small	High	Even	<u>Both of these distances should be further than when the hitch was a low height, but that's NOT what Group 1 should focus on.</u>

C: The smaller tires allow the tractor to pull better than the larger tires.

E: At both hitch heights, the run with the smaller tires went further than the run with the larger tires. Specific data from the above table should be referenced to support the claim.

R: While participants may not know this yet, because you are applying the force to the tire with a gear smaller than the diameter of the tire, force is actually decreased. The larger the tire, the more the force is decreased because of a concept called mechanical advantage. It's like trying to push open a door by pushing by the hinge (as opposed to pushing out where the handle is).

Name: _____

Class: _____

Claim Evidence Reasoning (C.E.R.) Framework: Group 2 – Answer Key

Directions: Complete the data table as well as the claim, evidence, and reasoning below.

Tires	Pinion Gear	Spur Gear	Hitch	Weights	Pull (m) and comments
Large	<u>Small</u>	Small	Low	Even	<u>Distances will vary based on your conditions, but the small gear should pull further than the large gear.</u>
Large	<u>Large</u>	Small	Low	Even	
Large	<u>Large</u>	Small	High	Even	<u>Distances will vary based on your conditions, but the small gear should pull further than the large gear.</u>
Large	<u>Small</u>	Small	High	Even	<u>Both of these distances should be further than when the hitch was at a low height, but that's NOT what Group 2 should focus on.</u>

C: The small pinion gear (10 teeth) pulls better than the large pinion gear (12 teeth). While it's easier to see size, for this part, the more important idea to focus on is the number of teeth. It's appropriate to redirect participants towards that concept.

E: At both hitch heights, the small pinion gear pulls further than the large pinion gear. Specific data from the above table should be referenced to support the claim.

R: The mechanical advantage (MA) of a set of gears is the number of teeth on the spur gear divided by the number of teeth on the pinion gear. Since 10 is less than 12, dividing by a smaller number gives a bigger answer (a bigger MA).

Name: _____

Class: _____

Claim Evidence Reasoning (C.E.R.)

Framework: Group 3 – Answer Key

Directions: Complete the data table as well as the claim, evidence, and reasoning below.

Tires	Pinion Gear	Spur Gear	Hitch	Weights	Pull (m) and comments
Large	Small	<u>Small</u>	Low	Even	<u>Distances will depend on your conditions, but the larger the spur gear, the further the sled should go.</u>
Large	Small	<u>Medium</u>	Low	Even	
Large	Small	<u>Large</u>	Low	Even	
Large	Small	<u>Small</u>	High	Even	<u>Distances will depend on your conditions, but the larger the spur gear, the further the sled should go.</u>
Large	Small	<u>Medium</u>	High	Even	
Large	Small	<u>Large</u>	High	Even	

C: The larger and more teeth on the driven gear, the better the tractor pulls. While it's easier to see size, for this part, the more important idea to focus on is the number of teeth. It's appropriate to redirect participants towards that concept.

E: At both hitch heights, the large (60-tooth) spur gear pulls furthest and the small (50-tooth) driven gear pulls the shortest. Specific data from the above table should be referenced to support the claim.

R: The mechanical advantage of a set of gears is the number of teeth on the spur gear divided by the number of teeth on the pinion gear. Since $60 > 55 > 50$, the answers will be in the same order. The most teeth = the biggest MA, since the number of spur gear teeth is on the top (numerator).

Name: _____

Class: _____

Claim Evidence Reasoning (C.E.R.) Framework: Group 4 – Answer Key

Directions: Complete the data table as well as the claim, evidence, and reasoning below.

Tires	Pinion Gear	Spur Gear	Hitch	Weights	Pull (m) and comments
Large	Small	Small	<u>Low</u>	Even	Distances will vary based on your testing conditions but the results should be stark. With the hitch in the lowest position, the distance should be the shortest and with the hitch in the highest position, it should be the longest.
Large	Small	Small	<u>Medium</u>	Even	
Large	Small	Small	<u>High</u>	Even	

C: The higher the hitch, the better the tractor pulls.

E: The distance that the tractor pulled the sled with the hitch in the highest position was further than the distance at the medium hitch position, which was further than when the hitch was at the lowest position. Specific data from the above table should be referenced to support the claim.

R: Again, while the participants might not yet understand why, it has do with the directions of force. When the hitch is at a higher position, the towing string is at a steeper angle. This causes the weight of the sled to pull down on the rear of the tractor, increasing its grip (friction, but good friction in this case) on the floor. In addition, the upward pull of the string on the sled decreases the contact of the skid plate on the floor, decreasing the resistance (also friction, but bad friction in this case). This (good) friction allows efficient transfer of the force from the electric motor, through the gears and tires, and into a forward push without spinning out as much.

Name: _____

Class: _____

Claim Evidence Reasoning (C.E.R.) Framework: Group 5 – Answer Key

Directions: Complete the data table as well as the claim, evidence, and reasoning below.

Tires	Pinion Gear	Spur Gear	Hitch	Weights	Pull (m) and comments
Large	Small	Small	Low	<u>Even</u>	<u>Distances will vary based on your conditions, but the greatest distance should be achieved with the most weight as far back as possible (middle max), with even next, and front max as well as none pulling the least distance.</u>
Large	Small	Small	Low	<u>Front max</u>	
Large	Small	Small	Low	<u>Middle max</u>	
Large	Small	Small	Low	<u>None</u>	

C: The tractor pulls best with the most weight towards the back.

E: The distances with the most weight in the back (middle max) were the longest. The distance pulled with even weight distribution pulled a medium distance. The distances pulled with no weights or weight maxed in the front pulled the shortest distance. Specific data from the above table should be referenced to support the claim.

R: Again, participants might not be able to articulate a reasoning yet (but some may know from real life about putting weight in the back of a rear-wheel-drive truck). The more weight over the drive tires, the more contact (normal force) between the tires and the surface, and the more traction (good friction) that should be achieved. This friction allows efficient transfer of the force from the electric motor, through the gears and tires, and into a forward push without spinning out as much.

Name: _____ Class: _____

Claim Evidence Reasoning (C.E.R.) Framework Summary

Directions: Complete the Claim and Reasoning table below for each variable analyzed (your evidence is in your data table for reference).

Variable	Result	Reasoning
Tire diameter		
Pinion gear		
Spur gear		
Hitch		
Weight distribution		

Name: _____

Class: _____

Claim Evidence Reasoning (C.E.R.) Framework

Summary – Answer Key

Directions: Complete the Claim and Reasoning table below for each variable analyzed (your evidence is in your data table for reference).

Variable	Result	Reasoning
Tire diameter	<u>Smaller is better</u>	<u>Because you're applying the force to the tire with a smaller gear than the diameter of the tire, force is actually decreased. The larger the tire, the more the force is decreased because of a concept called mechanical advantage.</u>
Pinion gear	<u>Fewer teeth is better</u>	<u>The mechanical advantage (MA) of a set of gears is the number of teeth on the spur gear divided by the number of teeth on the pinion gear. Since 10 is less than 12, dividing by a smaller number gives a bigger answer (a bigger MA).</u>
Spur gear	<u>More teeth is better</u>	<u>The mechanical advantage of a set of gears is the number of teeth on the spur gear divided by the number of teeth on the pinion gear. Since $60 > 55 > 50$, the answers will be in the same order. The most teeth = the biggest MA, since the number of spur gear is on the top (numerator).</u>
Hitch	<u>Higher is better</u>	<u>When the hitch is at a higher position, the towing string is at a steeper angle. This causes the weight of the sled to pull down on the rear of the tractor, increasing its grip (friction, but good friction in this case) on the floor. In addition, the upward pull of the string on the sled decreases the contact of the skid plate on the floor, decreasing the resistance (also friction, but bad friction in this case). This (good) friction allows efficient transfer of the force from the electric motor, through the gears and tires, and into a forward push without spinning out as much.</u>
Weight distribution	<u>More weight, and more weight in the back is better</u>	<u>The more weight over the drive tires, the more contact (normal force) between the tires and the surface, and the more traction (good friction) that should be achieved. This friction allows for efficient transfer of the force from the electric motor, through the gears and tires, and into a forward push without spinning out as much.</u>

Sources

Meacham, B. (2017). *Implementing the Claim, Evidence, Reasoning Framework in the Chemistry Classroom*. Chem Ed Xchange, <https://www.chemedx.org/article/implementing-claim-evidence-reasoning-framework-chemistry-classroom>. Accessed 22, January, 2022.

Lesson Three – Gears and Tires

Lesson Overview

Participants now examine the physics behind the first three variables. Participants will compare the theoretical prediction of the best configuration for pinion and spur gears and wheels to their observations from lesson two.

Lesson Objectives

After completing this lesson, participants will be able to

- Calculate mechanical advantage for a set of gears
- Choose the appropriate gears for speed or power
- Calculate mechanical advantage for a tire and axle system
- Choose the appropriate tire and axle configuration for speed or power
- Calculate mechanical advantage for a compound (machine) system

Lesson at a Glance

Activity	Materials	Preparation	Approximate class time
FOCUS	1. <i>Gears and Tires</i> slide presentation (slides 2-3) 2. Gear ratio video (optional): https://www.youtube.com/watch?v=ia463NahG5Q	1. Prepare video for viewing. 2. Prepare the <i>Gears and Tires</i> slide presentation for viewing (slides 2-3)	5 minutes
LEARN	1. <i>Gears and Tires</i> slide presentation (slides 4-15) 2. <i>Calculating Mechanical Advantage</i> worksheet 3. <i>Calculating Mechanical Advantage</i> worksheet – Answer Key 4. Calculators, cell phones, computers, etc.	1. Print/photocopy <i>Calculating Mechanical Advantage</i> worksheet (one per participant) 2. Prepare the <i>Gears and Tires</i> slide presentation for viewing (slides 4-15) 3. Distribute calculators, computers, and/or allow for cell phone use etc. (one per participant)	45 minutes
REVIEW	1. <i>Gears and Tires</i> slide presentation (slide 16) 2. <i>Gears and Tires Quiz</i> 3. <i>Gears and Tires Quiz</i> – Answer Key	1. Prepare the <i>Gears and Tires</i> slide presentation for viewing (slide 16). 2. Ensure that participants still have access to their <i>C.E.R. Framework</i> worksheet, <i>C.E.R. Summary</i> worksheet, and <i>Divide and Conquer</i> – Data Table from lesson two 3. Print/photocopy <i>Gears and Tires Quiz</i> (one per participant)	10 minutes

Lesson Three – Gears and Tires

FOCUS: Review of Lesson Two Conclusions

5 minutes

Purpose:

Participants review the conclusions regarding gears and tires from lesson two in order to situate today's learning in context.

Materials:

- *Gears and Tires* slide presentation for viewing (slides 2-3).
- Gear ratio video (optional):
<https://www.youtube.com/watch?v=ia463NahG5Q>

Facilitation Steps:

1. Show the participants slide two and review the *C.E.R. Summary* from lesson two.

Slide 2: Review C.E.R. Summary

While participants may have reasoning from lesson two, today they're going to learn the actual scientific principle at work.

At the end of the lesson, participants can compare these principles to their explanations from lesson two to see how much they've grown.

Review with participants slide three to focus the day on the questions we wish to answer for each variable.

Slide 3: Analyzing the Data

2. The optional video is about eight minutes long and shows that with a low gear ratio, the truck has better acceleration in bad conditions. This is not an exciting video, but they do a good job of recording the data in the top corner.

Alternate idea, would be to assign groups the video to watch as homework. Then you can discuss it briefly in class.

Lesson Three – Gears and Tires

LEARN: Calculating Mechanical Advantage

45 minutes

Purpose:

Participants will be introduced to calculating the mechanical advantage for gears, wheels and axles, and a compound machine.

Materials:

- *Gears and Tires* slide presentation (slides 4-15)
- *Gears and Tires* worksheet (one per participant)
- *Gears and Tires* – Answer Key

Facilitation Steps

1. Distribute *Gears and Tires* worksheet (one per participant).
2. Show *Gears and Tires* slide presentation (starting at slide 4).

Slide 4: Mechanical Advantage, Simple Machines, and Gears

Introduces the concept of mechanical advantage (no notes).

Slide 5: Gears

<https://www.omnicalculator.com/physics/gear-ratio> is a handy tool to calculate MA (mechanical advantage), torque, and speed.

For our combinations:

$$60/10 = 6 \text{ (i.e., force out = 6x the force in)}$$

$$55/10 = 5.5$$

$$50/10 = 5$$

$$60/12 = 5$$

$$55/12 = 4.58$$

$$50/12 = 4.17 \text{ (i.e., force out = just a over 4x force in)}$$

Slide 6: Force and Distance

The in and out flip for distance.

Depending on the algebra skills of your participants, you may need to present each of these as three formulas instead of one:

- $MA = \text{Force}_{\text{out}}/\text{Force}_{\text{in}}$,
 $\text{Force}_{\text{out}} = MA \times \text{Force}_{\text{in}}$,
 $\text{Force}_{\text{in}} = \text{Force}_{\text{out}}/MA$ and
- $MA = \text{Distance}_{\text{in}}/\text{Distance}_{\text{out}}$,
 $\text{Distance}_{\text{in}} = MA \times \text{Distance}_{\text{out}}$,
 $\text{Distance}_{\text{out}} = \text{Distance}_{\text{in}}/MA$

The second bulleted formula works for speed as well (speed out in feet/s or meters/s or rpm).

If the pinion gear turns at 200 rpm with $MA = 4$, then the spur gear turns $\text{Speed}_{\text{out}} = \text{Speed}_{\text{in}}/MA = 200/4 = 50$ rpm.

If participants are familiar with other concepts (such as torque), you can discuss these as well.

The first formula works for torques as well ($\text{Torque}_{\text{in}} \times MA = \text{Torque}_{\text{out}}$). For 200 pound-feet of torque and $MA = 4$,

200 pound-feet of torque in $\times 4 = 800$ pound-feet of torque (or Newton-meters in metric).

Slide 7: More Examples

After this slide, participants should answer question 2 on their *Gears and Wheels* worksheet.

As participants might know, Ford put a 5L engine in its Mustangs and in its F-150 pickups, with dramatically different results. You don't use a Mustang to haul, you don't drag race an F-150. Why? (Well, because drag racing is illegal). But seriously, difference in how the engine is tuned and, more importantly, the transmission/gear box will determine whether that force and speed is turned into more force (for hauling) or more speed.

In the slide's example, if we reversed the spur and pinion gears, 14 N of force would decrease to 4 N and 140 rpm would go up to 490 rpm (Mustang gearing).

For pulling, we want truck gearing. Small pinion gear and large spur gear.

Slide 8: Tire and Axle

Of the six simple machines, the Tire and Axle is the most misunderstood. Wheels to reduce friction are far more common than wheels used to create leverage. Boat lifts can multiply a relatively small force to lift a boat.

Slide 9: Boat Lift

This is a great example of the power of a simple machine to multiply force.

Slide 10: Mechanical Advantage

All the tires are bigger than all the gears. This means all of these will technically reduce the force slightly from the spur gear to the axle.

Spur Gear Diameters: Small 5.0 cm, Medium 5.75 cm, Large 6.25 cm

Tire diameter: Small 6.75 cm, Large 7.25 cm

Slide 11: Tire and Gear Combo

If you need to work a problem for them: *The biggest gear with the small tire results in the least reduction of force.*

The biggest tire with the smallest gear results in the most reduction of force, but the biggest increase in speed. MA represents the amount the force is increased. The flipped fraction represents the amount that the speed or distance is increased. $1/MA = \text{amount speed is increased}$. $1/0.69 = 1.45$. While the force is decreased to only 0.69 (69%) of the original, speed would be increased by 45% (0.45).

If the original force coming out of the drive gear was 10 N, the large tire and small gear combination would only put out 6.9 N against the ground.

If large gear and small tire were used instead, 9.3 N would be put out.

Slide 12: Examples

Force out = $MA \times \text{Force in}$ = $0.74 \times 40 \text{ N}$ = 29.6 N (works in pounds of force or torques as well)

Speed out = $\text{Speed in}/MA = (3 \text{ m/s})/0.79 = 3.80 \text{ m/s}$ (works for inches/second, miles/hour, etc.)

For tires and axles, this DOES NOT work for rpm (revolutions per minute). The tire and the axle have the same rpm, but the further out you are, the faster you travel (if you have ever been on a merry-go-round, you are familiar with this phenomenon. The merry-go-round is spinning at the same rates (rpm), but you are moving faster (m/s, mph) the further out from the center you go.

Slide 13: Compound Machines (no notes)

Slide 14: Compound Machine Examples (no notes)

Slide 15: What About Our Combinations?

The total MA is the product of the individual MAs of the machines (or gears) that make it up.

The MA from the pinion to spur gear $>4x$. (4.17, 4.58, 5, 5, 5.5 or 6)

The MA from the gear to tire $<1x$ (0.69, 0.74, 0.79, 0.85, 0.86, 0.93)

Overall, the MA delivered to the wheels is at least $4.17 \times 0.69 = 2.88$ (for large pinion gear, small spur gear, big tire) and at most $6 \times 0.93 = 5.58$ (for small pinion gear, large spur gear, small tire).

This is important. All things considered, the right choice of gears and tires should give almost exactly 2x as much force as the wrong choice - if we were aiming for force.

You could have participants drag race the tractors too, and then the opposite gearing would give the greatest top end speed (although the power gearing could get better initial acceleration). This would be two different additional experiments. The best setup for maximum acceleration is a 2-meter sprint and the best setup for top speed is a 10-meter or longer track in a hallway.

Slide 16: Check Lesson 2 Reasoning

Because you're applying the force to the tire with a smaller gear than the diameter of the tire, force is decreased. The larger the tire, the

more the force is decreased because of a concept called mechanical advantage.

The mechanical advantage (MA) of a set of gears is the number of teeth of the spur gear divided by the number of teeth of the drive gear. Since 10 is less than 12, dividing by a smaller number gives a bigger answer (*a bigger MA*).

The MA of a set of gears is the number of teeth of the driven gear divided by the number of teeth of the drive gear. Since $60 > 55 > 50$, the answers will be in the same order – the most teeth = the biggest MA, since spur gear number of teeth is on the top (numerator).

Name: _____ Class: _____

Gears and Tires

Directions: Solve each problem as directed in the presentation.

- After slide 5, calculate the mechanical advantage for each of the possible gear combinations from lesson two using the data you collected in lesson one. Show your work.

Pinion Gear	Spur Gear	Mechanical Advantage
Small	Small	
Small	Medium	
Small	Large	
Large	Small	
Large	Medium	
Large	Large	

- After slide 7, if your electric motor spun at 180 rpm and 10 N of force, how fast (rpm) and forceful (N) would it turn the spur gear for each combination below? Show your work.

Pinion Gear	Spur Gear	MA from Q1	Force $\text{Force}_{\text{out}} = \text{MA} \times \text{Force}_{\text{in}}$	RPM $\text{Speed}_{\text{out}} = \text{Speed}_{\text{in}}/\text{MA}$
Small	Small			
Small	Large			
Large	Small			

3. After slide 10, calculate the MA for each of our tire and axle combinations, using the data from lesson one.

Tire Diameter	Spur Gear Diameter	MA $MA = D_{in}/D_{out}$
Small	Small	
Small	Medium	
Small	Large	
Large	Small	
Large	Medium	
Large	Large	

4. After slide 12, if your small spur gear was turning with an edge speed of 0.25 meters per second and 4.0 N of force, (a) how fast and (b) with how much force would the small tire turn?
- a.
- b.
5. After slide 15, (a) what is the MA for each of the combinations below? If the force applied from the pinion gear was 8 N and it spun at 3.0 m/s, (b) how much force and (c) how fast would the edge of the tire spin?

Pinion Gear	Spur Gear	Tire	(a) MA total $MA_T = MA_1 * MA_2$	(b) Force out $F_o = F_{in} * MA_T$	(c) Speed out $S_o = S_{in}/MA_T$
Large	Medium	Large			
Small	Large	Small			

Name: _____ Class: _____

Gears and Tires – Answer Key

Directions: Solve each problem as directed in the presentation.

- After slide 5, calculate the mechanical advantage for each of the possible gear combinations from lesson two using the data you collected in lesson one. Show your work.

Pinion Gear	Spur Gear	Mechanical Advantage
Small 10 teeth	Small 50 teeth	$50/10 = 5$
Small 10 teeth	Medium 55 teeth	$55/10 = 5.5$
Small 10 teeth	Large 60 teeth	$60/10 = 6$ (i.e., force out = 6x the force in)
Large 12 teeth	Small 50 teeth	$50/12 = 4.17$ (i.e., force out = just over 4x force in)
Large 12 teeth	Medium 55 teeth	$55/12 = 4.58$
Large 12 teeth	Large 60 teeth	$60/12 = 5$

- After slide 7, if your electric motor spun at 180 rpm and 10 N of force, how fast (rpm) and forceful (N) would it turn the spur gear for each combination below? Show your work.

Pinion Gear	Spur Gear	MA from Q1	Force $\text{Force}_{\text{out}} = \text{MA} \times \text{Force}_{\text{in}}$	RPM $\text{Speed}_{\text{out}} = \text{Speed}_{\text{in}}/\text{MA}$
Small 10 teeth	Small 50 teeth	5	$10 \times 5 = 50 \text{ N}$	$180 \text{ rpm} / 5 = 36 \text{ rpm}$
Small 10 teeth	Large 60 teeth	6	$10 \times 6 = 60 \text{ N (most)}$	$180 \text{ rpm} / 6 = 30 \text{ rpm}$ (slowest)
Large 12 teeth	Small 50 teeth	4.17	$10 \times 4.17 = 41.7 \text{ N (least)}$	$180 \text{ rpm} / 4.17 = 43.2 \text{ rpm}$ (fastest)

3. After slide 10, calculate the MA for each of our tire and axle combinations, using the data from lesson one.

Tire Diameter	Spur Gear Diameter	MA $MA = D_{in}/D_{out}$
Small 6.25cm	Small 5.0cm	$5.0/6.25 = 0.80$
Small 6.25cm	Medium 5.75cm	$5.75/6.25 = 0.92$
Small 6.25cm	Large 6.25cm	$6.25/6.25 = 1.0$ decreases force the least, increases speed the least.
Large 7.25cm	Small 5.0cm	$5.0/7.25 = 0.69$ decreases force the most, increases speed the most.
Large 7.25cm	Medium 5.75cm	$5.75/7.25 = 0.79$
Large 7.25cm	Large 6.25cm	$6.25/7.25 = 0.86$

4. After slide 12, if your small spur gear was turning with an edge speed of 0.25 meters per second and 4.0 N of force, (a) how fast and (b) with how much force would the small wheel turn?

- a. **$MA = 0.74$. To find the $speed_{out}$, divide the $speed_{in}$ by MA. $0.25m/s$ divided by $0.74 = 0.34m/s$. The speed was increased.**
- b. **$MA = 0.74$. To find the $force_{out}$, multiply the $force_{in}$ by MA. 4.0 N multiplied by $0.74 = 2.96\text{ N}$. The force was decreased.**

5. After slide 15, (a) what is the mechanical advantage for each of the combinations below? If the force applied from the pinion gear was 8 N and it spun at 3.0m/s, (b) how much force and (c) how fast would the edge of the tire spin?

Pinion Gear	Spur Gear	Tire	(a) MA total $MA_T = MA_1 * MA_2$	(b) Force out $F_o = F_{in} * MA_T$	(c) Speed out $S_o = S_{in}/MA_T$
Large	Medium	Large	$4.58 * 0.79 = 3.62$	$3.62 * 8N = 29\text{ N}$	$3.0/3.62 = 0.83m/s$
Small	Large	Small	$6.00 * 0.93 = 5.58$	$5.58 * 8\text{ N} = 44.6\text{ N}$	$3.0/5.58 = 0.54m/s$

Lesson Three – Gears and Tire

REVIEW: Reasoning Statements

10 minutes

Purpose:

Participants review and modify their reasoning statements from their *C.E.R. Framework* worksheets and *C.E.R. Summary* worksheet from lesson two, based on the scientific principles discussed and practiced today. Note: Groups 4 and 5 will only be able to modify the summary worksheet as the principles explaining their variable will not be discussed until tomorrow.

Materials:

- *C.E.R. Framework* worksheets, *C.E.R. Summary* worksheets, and *Divide and Conquer* – Data Table worksheets from lesson two
- *Gears and Tires Quiz*
- *Gears and Tires Quiz* – Answer Key

Facilitation Steps:

1. Participants should get out their *C.E.R. Framework* worksheets, *C.E.R. Summary*, and *Divide and Conquer* – Data Table worksheets from lesson two.
2. Participants should review and modify (if necessary) their C.E.R. statements from lesson two. While their trend (and thus their claim and evidence) should remain the same, it's likely that they now have a better understanding of gears, tires, axles, and mechanical advantage. They can now give a more informed reasoning/explanation that more closely matches the keys provided in lesson two.
3. If, after understanding the science, the claim, and especially evidence doesn't match, please

handle carefully. There are several important ideas to balance:

- a. You want them to walk away with the correct understanding.
- b. You want to respect their thought process on the conclusion.
- c. It's not scientifically valid to throw out data just because it doesn't agree with what a person thought should happen.

In a classroom of infinite time, the best option would be to retest those specific trials and make sure that the control variables were carefully monitored. Was each trial done on the same tractor? Same driver? Was the tractor's battery topped off before each trial? Were the tires wiped free of dust each time? Was the path swept? Were the weights stacked the same in the weight box on the sled? With more time (or sleds), each test could have been performed multiple times initially which would also tend to decrease the likelihood of odd results.

If there is not time for additional testing, or additional testing produces the same result, it can be useful to save data from a year where you got good data, to discuss in years when the data collection went less well.

4. Distribute the *Gears and Tires Quiz* and give participants five minutes to complete it.

Name: _____

Class: _____

Gears and Tires Quiz

Directions: Indicate the correct answer or answers for each question.

1. Which pinion gear would have the greatest mechanical advantage when used with a 72-tooth spur gear?
 - a. 8 tooth
 - b. 9 tooth
 - c. 12 tooth
 - d. 18 tooth
2. Which spur gear would have the greatest mechanical advantage when used with a 10-tooth pinion gear?
 - a. 40 tooth
 - b. 50 tooth
 - c. 60 tooth
 - d. 70 tooth
3. A 10-tooth pinion gear is used with a 30-tooth spur gear. 5.0 N of force is applied by the pinion gear. How much force does the spur gear produce?
 - a. 1.7 N
 - b. 5.0 N
 - c. 15 N
 - d. 60 N
4. 10 N of force is applied to a 5.0-cm gear on the same axle as a 10-cm tire. How much force can the tire apply when it spins?
 - a. 5.0 N
 - b. 10 N
 - c. 20 N
 - d. 50 N
5. A compound machine is made of two simple machines, with mechanical advantages of 2 and 5 respectively. What is the total mechanical advantage of this compound machine?
 - a. 3
 - b. 7
 - c. 10
 - d. 25

Name: _____

Class: _____

Gears and Tire Quiz – Answer Key

Directions: Indicate the correct answer or answers for each question.

1. Which pinion gear would have the greatest mechanical advantage when used with a 72-tooth spur gear?
 - a. **8 tooth (MA = $\frac{\text{\#teeth}_{\text{spur}}}{\text{\#teeth}_{\text{pinion}}}$. The fewer pinion teeth, the better)**
 - b. 9 tooth
 - c. 12 tooth
 - d. 18 tooth

2. Which spur gear would have the greatest mechanical advantage when used with a 10-tooth pinion gear?
 - a. 40 tooth
 - b. 50 tooth
 - c. 60 tooth
 - d. **70 tooth (MA = $\frac{\text{\#teeth}_{\text{spur}}}{\text{\#teeth}_{\text{pinion}}}$. The more spur teeth, the better)**

3. A 10-tooth pinion gear is used with a 30-tooth spur gear. 5.0 N of force is applied by the pinion gear. How much force does the spur gear produce?
 - a. 1.7 N
 - b. 5.0 N
 - c. **15 N (MA = $\frac{\text{\#teeth}_{\text{spur}}}{\text{\#teeth}_{\text{pinion}}}$. $30/10 = 3$. $\text{Force}_{\text{out}} = \text{Force}_{\text{in}} \times \text{MA}$. $5 \text{ N} \times 3 = 15 \text{ N}$)**
 - d. 60 N

4. 10 N of force is applied to a 5.0-cm gear on the same axle as a 10-cm tire. How much force can the tire apply when it spins?
 - a. **5.0 N (MA = $\frac{\text{distance}_{\text{in}}}{\text{distance}_{\text{out}}} = 5/10 = 0.5$. $\text{Force}_{\text{out}} = \text{Force}_{\text{in}} \times \text{MA}$. $10 \text{ N} \times 0.5 = 5 \text{ N}$)**
 - b. 10 N
 - c. 20 N
 - d. 50 N

5. A compound machine is made of two simple machines, with mechanical advantages of 2 and 5 respectively. What is the total mechanical advantage of this compound machine?
 - a. 3
 - b. 7
 - c. **10 (MA_t = MA₁ x MA₂. $2 \times 5 = 10$)**
 - d. 25

Lesson Four – Weight and Friction

Lesson Overview

Participants now examine the physics behind the last two variables. Participants will compare the theoretical prediction of the best configuration for weight distribution and hitch height to their observations from lesson two.

Lesson Objectives

After completing this lesson, participants will be able to:

- State and apply Newton's 3rd Law
- Define normal force

Lesson at a Glance

Activity	Materials	Preparation	Approximate class time
FOCUS	1. Videos related to friction and trucks (optional): • The difference snow tires make: https://www.youtube.com/watch?v=d332ZkNM_do • The difference weight in the back makes: https://www.youtube.com/watch?v=fcCMbfW42Zo	1. Prepare the video clips for viewing (optional)	10 minutes
LEARN	1. <i>Weight and Friction</i> slide presentation (slides 2-13) 2. <i>Weight and Friction</i> worksheet 3. <i>Weight and Friction</i> – Answer Key	1. Print/photocopy <i>Weight and Friction</i> worksheet (one per participant) 2. Prepare <i>Weight and Friction</i> slide presentation for viewing (slides 2-13)	40 minutes
REVIEW	1. <i>Weight and Friction</i> slide presentation (slide 14)	1. Prepare <i>Weight and Friction</i> slide presentation for viewing (slide 14) 2. Ensure that participants still have access to their <i>C.E.R. Framework</i> worksheet, <i>C.E.R. Summary</i> worksheet, and <i>Divide and Conquer</i> – Data Table from lesson two	10 minutes

Lesson Four – Weight and Friction

FOCUS: Friction Videos and Discussion

10 minutes

Purpose:

Participants can watch up to two videos which provide a real-world context for understanding the importance of weight in the back and friction in terms of the ability of a truck to accelerate.

Materials:

1. *C.E.R. Framework* worksheet, *C.E.R. Summary* worksheets, and *Divide and Conquer* – Data Table
2. Videos (optional)
 - Difference snow tires make:
https://www.youtube.com/watch?v=d332ZkNM_do
 - Difference weight in the back makes:
<https://www.youtube.com/watch?v=fcCMbfW42Zo>

Facilitation Steps:

1. Review the conclusions from lesson three. Did switching the gears or tires make a large difference in the tractor's ability to pull as science predicted?

For example, the force coming out of the tire from the small pinion gear, large spur gear, and small tire configuration should have been about double that of the large pinion gear, small spur gear, and large tire configuration. However, was the distance that the first configuration pulled the sled noticeably different from the distance that the second configuration pulled the sled, particularly if the hitch was in the low setting? Probably not. Why?
2. Participants may have noted on the *Divide and Conquer* – Data Table that the tires sometimes spun in place when the sled stopped. If any participants noticed this, ask, “What effect, if any, do you think these spinning tires had on the ability of the tractor to transfer force from the motor, through the gears, and to the tire?”

If the tires spun in place, it was the friction between the tires and the floor that gave out before the push of the electric motor. This is the key.

If the motor can push with 10 N, but the tires can only get 7 N of friction against the floor, the mechanical advantage doesn't help because 10 N of push is already more than the tires can accept, causing the tires to spin. Increasing the force to 20 (through a mechanical advantage of 2, through a combination of gears and tires) would theoretically increase the push to 20 N. However, if the tires still spin out at 7 N, the tractor may not go an inch further.

3. If your participants drive in a northern climate, an analogy to being stuck on ice/snow (or in the South, mud) might make sense to spur discussion. Once a car is stuck, pushing down harder on the gas does no good because, hard or soft, the tires just spin in place.
4. Depending on how productive the discussions are, you may or may not decide to show one or the other video. The first video (snow tires) is short and shows the value of tires with greater friction. While not part of this curriculum, testing the tires with and without the rubber bands or adding additional rubber bands could be an interesting extension after watching this video. The second video (weight in the back) is very relevant to what we are exploring today. This is a longer video, although the last half is about handling in the snow as opposed to just performance with weight in the back. If you show these videos, they provide a concrete opening for a discussion of friction in the main part of this lesson.

Lesson Four – Weight and Friction

LEARN: Weight Distribution on the Tractor

40 minutes

Purpose:

Participants learn about the factors affecting the force of friction and how friction relates to the distribution of weight and hitch height changed in lesson two.

Materials:

- *Weight and Friction* slide presentation (slides 2-13)
- *Weight and Friction* worksheet (one per participant)

Facilitation Steps:

1. Distribute the *Weight and Friction* worksheet to participants.
2. Start the *Weight and Friction* presentation.

Slide 2: Why didn't We Always See Day 3 Principles in Our Results?

We had various ways to increase the push of the tire against the ground (*changing the pinion gear/spur gear ratio, changing the tires*).

However, the issue is that the amount of push that the tires get against the floor is limited by Newton's 3rd law (*for every action, there is an equal and opposite reaction*). The push of the tire against the floor can't be greater than the amount of the friction of the tire against the floor. If the tires spin out, then they don't allow the motor → pinion gear → spur gear → tire to achieve its maximum push.

Slide 3: Newton's 3rd Law

Newton's 3rd law is problematic because it quickly leads to participants saying, "If the forces are equal and opposite, why does anything move?"

The solution to this is two bodies: The force of the tire on the road and the force of the road on the tire.

We then sum the forces (*Newton's 2nd Law*) on one body at a time. We sum the forces on the

tractor and that's only the road pushing back on the tractor vs. pull of the sled. We don't include the force of the tire pushing on the ground because that's a different body (on the ground).

The same will be true for the tractor and the sled. The sled pulls on the tractor as hard as the tractor pulls on the sled. Why does the sled move? Because we sum the forces on each object separately:

- The tractor: Force of the ground pushing back on the tires > force of the sled pulling against the tractor, causing the tractor to go forward.
- The sled: Force of the tractor pulling on the sled > force of the friction from the skid plate, causing the sled to go forward.
- Eventually, friction on the skid plate increases until it's bigger than the force of the tractor pulling on the sled (which slows the sled). Since the force of the sled pulling on the tractor is equal to the tractor pulling on the sled, eventually this is bigger than the push of the tires (which slows and stops the tractor).

Slide 4: Review From Lesson 1

Remember, the normal force is usually equal and opposite to the weight. The more weight, the more normal force. The more normal force, the more friction.

Slide 5: Gravity and Normal Force

The total weight of the tractor is about 5 N. Most of the weight is in the motor and battery and this weight is towards the rear of the tractor. This means more of the 5 N is over the rear tires.

If the rear tires spin out (*spin in place*), then lack of friction is preventing the motor and gears from delivering the full force possible to the tires.

There are two ways we can help this: Stickier tires or more weight over the back.

The force of friction can be calculated by multiplying the normal force by the coefficient of friction.

The normal force is what pushes back on something pushing into a surface. It's the resistance that keeps things from sinking into a surface. It's equal and opposite to the force pushing in. If you lean against a wall, it's the same thing. Your shoulder pushes into the wall, the wall pushes back, keeping you upright.

The coefficient of friction μ varies depending on the two surfaces rubbing together.

The size of the force of friction basically depends on weight. The more weight (force of gravity of F_g) pulling down over the tires, the bigger the F_N (normal force).

Slide 6: How Did We change the Normal Force?

If we look at the participant data from day two, then we should see that the arrangements with more weight total and especially more weight in the back should do better than combinations with less weight total/less weight in the back. Depending on how much data participants collected, they might have more or fewer rows than listed above. However, it's crucial when comparing any two rows that every other variable (tires, pinion gear, spur gear, hitch) are kept the same.

Slide 7: How Much Difference Do the Weights Make?

The weight in the front (*red arrow*) works like a teeter-totter with the front tire as a fulcrum (*red triangle*), lifting on the rear tire (*green arrow*).

The weight in the front is barely past the front tires, and the rear tires are a long way from the pivot, so the lift effect is quite small, even if most of the weights are in the front. However, it does decrease the normal force.

The weights themselves will have a small impact on the normal force.

One positive effect of weights in the front is that it prevents the tractor from doing a wheely (and keeps the steering in control) if the hitch is high and there is a lot of weight in the sled.

Slide 8: How Much Difference Do the Weights Make?

The weight in the middle (*blue*) also works like a lever, with the fulcrum at the front tire. This downward force applies a small downward force (*orange*) on the rear tires, slightly increasing the normal force (*purple*).

Again, shifting 10% of the weight around doesn't make a lot of difference. Since the rear tires are further from the fulcrum (front tires) than the middle posts, its force is lessened further. However, it will slightly increase the normal force, and thus slightly increase friction.

After slide 8, participants should answer questions 1-2 on their *Weight and Friction* worksheet.

Slide 9: The Height of the Hitch

The height of the hitch, showing a straight pull and an angled pull.

Slide 10: Complicated but Important

Depending on the mathematical ability of your class you can take this slide quite a bit further. If your participants understand basic right triangle trigonometry (*sine, cosine, tangent*) then if the force (F) is the green line, it can be broken into a vertical force ($F\sin\theta$) and a horizontal force ($F\cos\theta$) where θ is the angle the green line makes with the horizontal red line.

Slide 11: Implications to the Sled

The math, if appropriate to your class, in the slide is further explained below.

Weight (W , the force of gravity) pulls down with a force equal to the mass (m in kg) multiplied by 9.8 m/s^2 (the acceleration due to gravity, or g).

Or $W = m \times g$. $W = 5 \text{ kg} \times 9.8 \text{ m/s}^2 = 49 \text{ N}$ of weight pulling down, which would be balanced by 49 N of normal force pushing up. Friction would be found by taking the normal force times the coefficient of friction for the two surfaces (skid plate and flooring).

With 20 N of force, $20 \text{ N}\sin(15^\circ) = 5 \text{ N}$ of upward force and $20 \text{ N}\cos(15^\circ) = 19.3 \text{ N}$ of forward force. It barely decreases (less than 5% decrease) the forward force, but decreases the frictional force by just over 10%, making the sled easier to pull. But that isn't the whole story.

Slide 12: Implications to the Tractor

The pictures on slide 13 might help. While the individual weights have low mass and add little to F_{Normal} , the impact of the high hitch to the sled itself can be massive.

Since the high hitch could easily more than double the friction available, it makes all other modifications more effective. If the tires can only apply 6 N of friction, doubling the force on the tires from 6 to 12 by changing the gears does no good, since the limit is the friction (above 6 N, they just spin out). But with the hitch high, and potentially double the friction available (12 N), the tires will not spin, even when the force goes up to 12 N. The tractor pulls much harder.

However, it's even more complicated. The more the friction increases, the more the tractor can pull. The harder the tractor pulls diagonal up on the sled, the harder the sled pulls diagonal down on the tractor, increasing its normal force and friction, allowing an even stronger pull. A full analysis results in a differential equation (calculus).

Slide 13: For the Tractor

Diagram showing the increased downward force due to the angled pull and the resultant increased normal force. At this point, question 3 on the *Weight and Friction* worksheet should be answered.

Name: _____ Class: _____

Weight and Friction

Directions: Answer the questions below with information from the slide presentation.

1. Is the data from lesson two consistent with this explanation? Explain.
2. After viewing slides 7 and 8, what arrangement of weights should produce the best pull? Explain using the idea of the front tires as a fulcrum.
3. After viewing slide 13, explain in your own words why the height of the hitch matters.

Name: _____ Class: _____

Weight and Friction – Answer Key

Directions: Answer the questions below with information from the slide presentation.

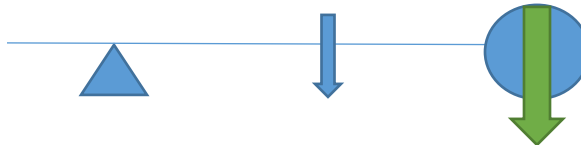
1. Is the data from lesson two consistent with this explanation? Explain.

Yes, the data from lesson two should show a better pull when the weight is shifted towards the middle posts and a weaker pull when the weight is shifted towards the front and removed altogether.

2. After viewing slides 7 and 8, what arrangement of weights should produce the best pull? Explain using the idea of the front tires as a fulcrum.

Even though there are 48 weights, since weights in the front actually decrease the normal force for the drive tires, 40 weights in the middle (the maximum that can be stacked and still attach the nuts) and leaving the other 8 weights off of the tractor entirely is probably the best design.

The best design would have maximum downward force (blue arrow) on the right side of the fulcrum (triangle, representing the front tires) and minimum downward force on the left side, since that would lift up at the rear tires (circle). To maximize friction, we want the green arrow as large as possible.



3. After viewing slide 13, explain in your own words why the height of the hitch matters.

When the hitch is low and the tow rope is flat, it has no effect on the tractor or sled, and only the other four variables matter, and then not much because there is not enough friction between the rear tires and the floor.

When the hitch is high, it has two impacts:

- It lifts up the skid plate, decreasing the (bad) friction and making the sled easier to pull.**
- It creates a downward force on the rear tires, increasing their (good) friction and making the tractor better at pulling.**

Lesson Four – Weight and Friction

REVIEW: Comparing Principles to Data

10 minutes

Participants review and modify their reasoning statements from their *C.E.R. Framework* worksheets and *C.E.R. Summary* worksheet from lesson two, based on the scientific principles discussed and practiced in this lesson.

Note: Groups 4 and 5 are the focus in this lesson. Groups 1-3 modified their sheets during lesson three.

Materials:

- *Weight and Friction* presentation (slide 14)
- *C.E.R. Framework* worksheets, *Divide and Conquer* – Data Table, and *C.E.R. Summary* worksheets

Facilitation Steps:

1. Show slide 14 of the *Weight and Friction* presentation.
2. Participants should get out their *C.E.R. Framework*, *C.E.R. Summary* and *Divide and Conquer* – Data Table worksheets from lesson two.
3. Participants should review and modify (if necessary) their C.E.R. statements from lesson two. While their trend (and thus their claim and evidence) should remain the same, it's likely that they now have a better understanding of weight distribution, normal force and friction, and can give a more informed reasoning/explanation that more closely matches the keys provided in lesson two.
4. If, after understanding the science, the claim and especially evidence doesn't match, please handle carefully. There are several important ideas to balance:
 - a. You want them to walk away with the correct understanding.

- b. You want to respect their thought process on the conclusion.
- c. It's not scientifically valid to throw out data just because it doesn't agree with what a person thought should happen.

In a classroom of infinite time, the best option would be to retest those specific trials and make sure that the control variables were carefully monitored.

Was each trial done on the same tractor? Same driver? Was the tractor's battery topped off before each trial? Were the tires wiped free of dust each time? Was the path swept? Were the weights stacked the same in the weight box on the sled?

With more time (or more sleds), each test could have been performed multiple times initially which would also tend to decrease the likelihood of odd results.

If there isn't time for additional testing, or additional testing produces the same result, it can be useful to save data from a year when you got good data to discuss in classes when the data collection didn't go as well.

In the end, it's unfortunate that the single most important variable influencing the tractor's ability to pull requires math at the the right triangle trigonometry level or higher to fully appreciate.

However, if we want the students to understand *why* the high hitch is better, this is the only option.

Hopefully this provides enough information for them to grasp the general concept.

Lesson Five – Tractor Pull!

Lesson Overview

This lesson is focused on the tractor pull itself. Participants will set up their tractors and pull against each other to pull the heaviest load the furthest.

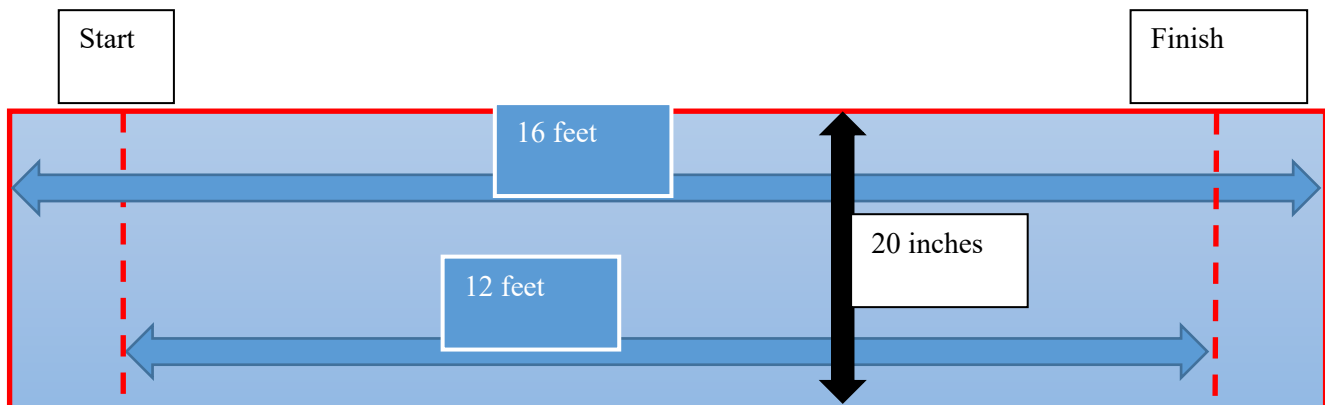
Lesson Objectives

After completing this lesson, participants will be able to:

- Reason semi-quantitatively about the amount of frictional force
- Reason semi-quantitatively about forces at an angle

Lesson at a Glance

Activity	Materials	Preparation	Approximate class time
FOCUS	1. <i>Your Tractor Setup</i> worksheet 2. Tractor kits 3. <i>Tractor Pull!</i> slide presentation(slides 2-5)	1. Copy/print <i>Your Tractor Setup</i> worksheet (one per participant) 2. Prepare tractor kits 3. Set up <i>Tractor Pull!</i> slide presentation	10 minutes
LEARN	1. <i>Tractor Pull!</i> slide presentation 2. Tractor kit (one per group) 3. Sled and weights 4. Tape to mark the course 5. Tape measure.	1. Mark off the course as shown below this table 2. Prepare <i>Tractor Pull!</i> slide presentation for viewing	45 minutes
REVIEW	1. Tractor Pull scores 2. <i>Your Tractor Setup</i> worksheet	1. Distribute <i>Your Tractor Setup</i> worksheet (one per participant)	5 minutes



Notes About the Tractor Pull

An actual tractor pull for distance is guaranteed to be an exciting event that participants will anticipate and can make an exciting “show” lesson. If appropriate, consider inviting the student news, the public, younger grades just touching on forces, etc. who could serve as an audience to attend, depending on the school setup.

Nevertheless, the following are some concerns to be aware of:

1. There is one best configuration of the tractor – one best gear ratio, one best hitch setting, one best tire choice, etc. that participants will systematically determine these in the first four days of the lesson. If they paid attention on days one through four, they should all use the exact same science to reach the same conclusion and use the same setup in the pull, theoretically resulting in a tie across the board.
2. It won't be a tie, but the reasons it won't be a tie will fall into three main categories:
 - a. Better tinkerers. There are minor modifications that can be made to the system that might give a slight edge. One of these, for example, is to give the hitch on the tractor a slight twist so that it's almost horizontal instead of vertical. This position slightly raises the lowest part of the hitch hook, making the angle the string forms with the sled a little steeper. It shifts just that much more weight onto the back tires for more traction and just that much more weight off the skid plate to reduce the resistance (friction) from the skid plate. This one can be explained as an extension of science concepts that we explored in day four. However, other changes might just “work” without lending themselves to easy scientific explanations. There are two other risks here:
 - i. Because the participants goal is a maximum pull, all of the pieces (tractor, sled, etc.) will be subjected to maximum stress and increase the likelihood of breakage.
 - ii. Where is the line between tinkering and cheating? What modifications to the system are allowed? Which will be explicitly forbidden? Which will constitute a gray area? Modifications (or attempted modifications) will also increase the likelihood of breakage and would be explicitly forbidden by any warranty (i.e. adding additional weights to the tractor, greasing the skid plate, sanding the skid plate, etc.). It's suggested that most/all modifications are forbidden, which will unfortunately be less fun, is not as rewarding of creativity, and tends to make the winner dependent on the other two factors.
 - b. There will be minor discrepancies in the machines. Some of these might have happened during manufacturing – battery A puts out a tiny fraction more peak volts or amps than battery B and has done so since they rolled off the manufacturing line. Others are likely to accumulate over time. Over time, all rechargeable batteries lose some capacity, the skid plates will wear smoother and produce less friction, etc.
Some of this variability could be controlled by making everyone use the same tractor. However, if everyone uses the same tractor, the process will go much slower (instead of five teams all preparing their tractors at the same time, then running them in quick succession, they will have to wait for each group to prepare the same one) and it's much more likely that the result will be a five-way tie.
On the other hand, participants could be very disappointed if they perceive that another group won the competition because the game was rigged (i.e. tractor A had a better battery than tractor B) and so won even though they didn't choose the scientifically best setup. A result such as that can also make the participants reach the conclusion that science doesn't actually matter in the real world.
 - c. Better preparation. Some groups will take the time to make sure they topped off the battery, wiped any dust off the tires, swept the floor of debris right before their run, etc. All of these

small changes should make a tiny difference (it's amazing how quickly accumulated dust decreases the traction of the tires).

If groups are allowed to set up their own sled, this preparation could extend to how the weights are stacked in the weight box, etc. One concern is that later groups have the advantage of getting to watch the previous groups prep their run, unless competitors are kept in another area between runs. Making sure that the first round is set so everyone has a full pull would decrease this threat.

A list of reasons for winning/losing other than better application of science are in the table below. Suggested forbidden modifications are in italics.

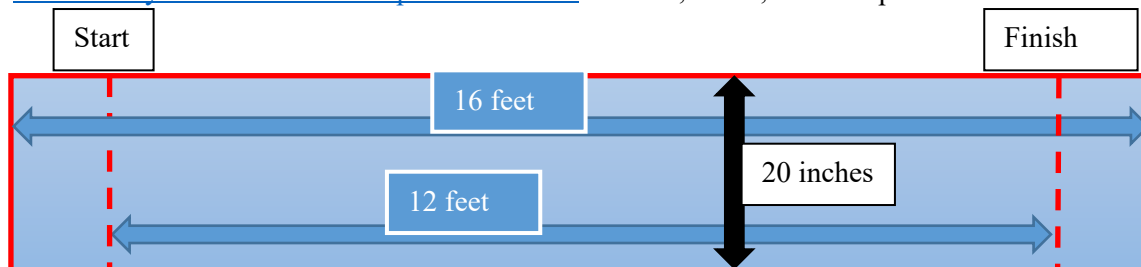
Better tinkerers (engineering/cheating?)	Minor discrepancies in the machine	More meticulous preparation before each run
Twisting the tractor's hitch	Manufacturing differences in the battery/motor	Wiping dust off tires
Lubricating the skid plate	Decreased performance in the battery over time	Sweeping dust off of path
Sanding/modifying the skid plate	Silicon bands lose grip or get stretched out	Recharging the battery
Tying a knot in the hitch rope to make it shorter and the angle steeper	Gears become worn	Carefully stacking the weights in the weight box a certain way to make it have a smoother (less friction) ride up the rails.

The skill of the driver may also make a difference.

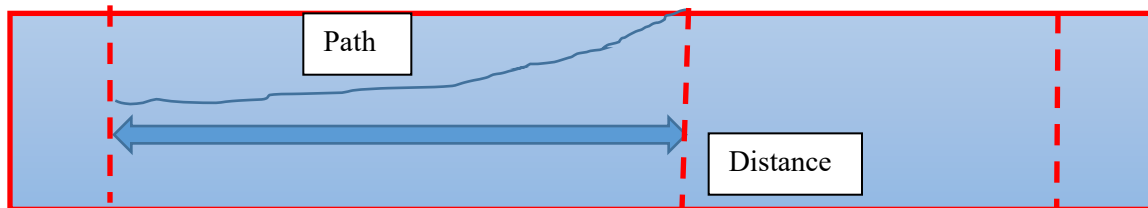
In the end, you probably don't want participants who work hard applying the science they learned to be beaten by an issue with their machine, or a trick another group tried. Nor may you want to risk damage to your machine through modification or pushing the limits to the extreme. But if you do, the rules below would be a place to start. With the underlined areas, you might consider a different option if you disagree with the analysis above.

Suggested Rules:

1. Find a clean, flat, smooth area suitable for the pull. It should be approximately 16 feet long to allow a full pull distance of about 12 feet, with room on both ends to set it up and catch it at the end.
2. Use only one sled. If you have purchased an additional sled, use only one sled for the competition. The instructor sets up the weights as evenly distributed in the weight box as possible and doesn't allow participants to modify that setup.
3. Mark all solid red lines in the diagram below with tape. Print the Track Setup Instruction from www.realityworks.com/rctractorpull-downloads for start, finish, and best pull markers.



4. The starting line should be clearly marked on the floor. A dot should be placed in the middle of the starting line. Each tractor should start the run with the same part of the apparatus (we suggest the hitch on the tractor) directly over the starting line center dot.
5. The finish line is slightly arbitrary. The sled has officially reached a “full pull” when the weight box makes it to the very top of the rails. This might happen at slightly less or greater actual distances depending on how the string wraps around the axle, etc. Please mark the finish line as close as possible to where this full pull typically occurs.
6. All participants are given 10 minutes to prepare their tractors. This includes topping off batteries, wiping tires, moving the hitch, inserting the appropriate gears and tires, distributing the weights on posts, etc. At the end of these 10 minutes, all participants must take their hands off their tractor. For the best competition, we suggest limiting the number of washer weights to 36 per tractor.
7. 3 lbs of weight should be placed in the weight box as a start. If all tractors are able to pull that weight, the weight should be increased by 3 lbs intervals, with only those tractors achieving a full pull at the previous weight being allowed to compete at the new weight. The starting weight would ideally be set at one of two places:
 - a. Just light enough that all tractors achieve a full pull, but most are weeded out after one successful full pull. This would give everyone a feeling of some success, but will take substantially more time.
 - b. Heavy enough that some tractors will not start at a full pull. This is more practical, but could demoralize some participants.
 - c. A compromise would be a 4-lb jump from round one to round two.
8. Determine a pull order randomly (ahead of time). Each group is given 2 minutes to attach their tractor and complete their pull.
9. Once the tractor starts, the pull is over if:
 - a. The tractor stops at any point (it’s not allowed to restart).
 - b. Any part of the tractor/sled completely crosses the side boundaries.
 - c. Anyone makes contact with the tractor/sled.
10. If there is a malfunction in the sled (a weight falls off, etc.) the group may be given another pull at the discretion of the teacher.
11. If the weight box moves all the way to the top of the sled, this is a full pull and the tractor moves on to the next round. If the tractor stops or goes outside of the lane before the weight box moves to the top of the sled, then this is a partial pull, and the distance from the starting point straight forward to the furthest distance the hitch moved should be recorded (not the length of the path the tractor and sled took).



12. All full pulls move to the next round, where additional weight is added and the process is repeated until only 1 or 0 tractors make a full pull.
13. Ranking:
 - a. 1st place – heaviest full pull. If no full pulls, then...
 - b. 1st place – furthest pull at heaviest weight
 - c. 2nd – Xth place, the remaining pulls at the heaviest weight in order of longest distance.

- d. Xth - Yth place, all the pulls at the next heaviest weight in order of longest distance, repeat as necessary.

Example: 10 teams, started at 2 lbs, all did a full pull. The weight was increased to 4 lbs on the second round, teams 1 and 3 did not do a full pull so are ranked 10th and 9th. At 6 lbs, team 2 was disqualified for touching their tractor during the pull and gets 8th (see below). With teams 10, 8, and 6 placing in 7th, 6th, and 5th based on distance, respectively.

Then the weight was increased to 8 lbs and places 4th through 2nd were decided by distance (teams 9, 7, and 4 respectively) with team 5 winning with a full pull. If team 5 had not had a full pull, but still had a distance (say 3.3 m) then the competition would still be over and places 1-4 would have all been determined by distances.

Team	Weight in Weight Box				Place
	3 lbs	6 lbs	9 lbs	12 lbs	
1	Full Pull	3.7 m			9 th
2	Full Pull	Full Pull	DQ		8 th
3	Full Pull	3.5 m			10 th
4	Full Pull	Full Pull	Full Pull	3 m	2 nd
5	Full Pull	Full Pull	Full Pull	Full Pull	1 st
6	Full Pull	Full Pull	3.2 m		5 th
7	Full Pull	Full Pull	Full Pull	2.7 m	3 rd
8	Full Pull	Full Pull	3.1 m		6 th
9	Full Pull	Full Pull	Full Pull	1.1 m	4 th
10	Full Pull	Full Pull	2.8 m		7 th

Troubleshooting:

1. Some people take competitions very seriously. Know how you will handle penalties in advance. On the above example, if they touched the tractor while it was still moving, disqualifying them and giving them 0 distance for that run would be appropriate. If, on the other hand, you had banned all modifications (see above) and they had installed a modification, disqualifying them for the whole event would be appropriate and they would get 10th place. Please make any of these rules known to the participants well ahead of time. If it isn't addressed before the competition starts, it's hard to enforce after.
2. Make sure participants understand the nuances. Measurement goes to the hitch (if this is not clear to your participants, pick the front of the tractor or rear of the sled, it might be easier to see/access). It's a straightforward measurement, not a curved line. The distance is the tiebreaker, not the most important number (i.e. in the example above, team 6's last pull (3.2 m) is much better than team 9's last pull (1.1 m). Team 6 might wonder why they placed behind team 9. It's because the first criteria is the most weight, and the second criteria is distance. Team 9 made it to the 8-lb round, team 6 did not. If it helps with your participants, consider putting in a number for full pull (3.6 m) rather than writing full pull (thus 3.6 m at the same weight is longer than team 6's pull of 3.2 m, which makes this nuance clearer).
3. Other nuances will emerge over time.
4. Make sure you have fun!

Lesson Five – Tractor Pull!

FOCUS: Tractor Pull Set Up

10 minutes

Purpose:

Participants apply what they learned in lessons one through four to set up their tractor.

Materials:

- Tractor kits (one per group)
- *Your Tractor Setup* worksheets (one per participant)
- *Tractor Pull!* slide presentation

Facilitation Steps:

1. Show slides 3-5 and discuss the rules.

Slide 2: Using What You Learned

Participants should write their combination of gears, tires, weights, and hitch used on the *Your Tractor Setup* worksheet.

We suggest limiting the number of washer weights to 36 per tractor for the best competition.

Slide 3: Rules

These are only suggestions. Consider modifying as appropriate for your situation.

Someone (you or a para-professional, teaching aide, etc.) should oversee the sled is reset between each run. The weights should be stacked in the sled in a uniform manner from run to run. If no one is available to help, this can be done by participants but dramatically increases the opportunity for skullduggery.

Slide 4: How Distance Will Be Measured

You are free to choose another point if it's easier to measure (nose of the tractor, back of the sled, etc.). Just make sure this is communicated clearly.

Slide 5: Rules (no notes)

Name: _____ Class: _____

Your Tractor Setup

Directions: Answer the following questions.

1. Indicate which setting you used for each variable and your reasoning.

Variable	Choice	Reasoning
Pinion gear		
Spur gear		
Tire size		
Weight distribution		
Hitch height		

2. Were the results of the tractor pull logical in light of the scientific principles studied? Why or why not?

Your Tractor Setup – Answer Key

Directions: Answer the following questions.

1. Indicate which setting you used for each variable and your reasoning.

Variable	Choice	Reasoning
Pinion gear	ANSWERS WILL VARY, But 10-tooth gear is likely	ANSWERS WILL VARY, But, fewer teeth on the spur gear should increase the MA.
Spur gear	ANSWERS WILL VARY, but the large, 60-tooth gear is likely	ANSWERS WILL VARY, but, more teeth on the spur gear should increase the MA. A larger gear should give a better MA for the tire and axle.
Tire size	ANSWERS WILL VARY, but, the small tire is likely.	ANSWERS WILL VARY, but, the smaller tire should have a better MA for the tire and axle.
Weight distribution	ANSWERS WILL VARY, but the setting with the most weights on the middle posts is likely.	ANSWERS WILL VARY, but the more weight as far back as possible (and none in front of the front tires) should maximize the normal force on the rear tires and maximize the friction (traction) they can get.
Hitch height	ANSWERS WILL VARY, but, the highest setting is likely.	ANSWERS WILL VARY, but the angled pull increases the normal force and traction of the tractor, and decreases the friction of the sled.

2. Were the results of the tractor pull logical in light of the scientific principles studied? Why or why not?

ANSWERS WILL VARY, but hopefully they were and match the setup above.

Lesson Five – Tractor Pull!

LEARN: The Competition

45 minutes

Purpose:

Participants attempt to pull the most weight the greatest distance.

Materials:

- Tractor kits (one per group)
- *Tractor Pull!* slide presentation (slide 6)
- Sled and weights
- Marked tractor pull course

Facilitation Steps:

1. Determine a pull order randomly (ahead of time).
2. Display *Tractor Pull!* presentation, slide 6 (scoring).
3. Find a clean, flat, smooth area suitable for the pull. It should be at least 16 feet long to allow a full pull distance of about 12 feet, with room on both ends to set it up and catch it at the end.
4. Use only one sled. The instructor (or designee) sets up the weights the weight box and does not allow participants to modify that setup.
5. The finish line is slightly arbitrary. The sled has officially reached a “full pull” when the weight box makes it to the very top of the rails. This might happen at slightly less or greater actual distances depending on how the string wraps around the axle, etc. Please mark the finish line as close as possible to where this full pull typically occurs in your setup.
6. All participants were given 10 minutes to prepare their tractors (in Focus). This includes topping off batteries, wiping tires, moving the hitch, inserting the appropriate gears and tires, distributing up to 36 washer weights on posts and axle, etc. At the end of these 10 minutes, all participants must take their hands off their tractor.
7. Place 3 lbs of weight in the weight box as a start. If all tractors are able to pull that weight,

the weight should be increased by 3 lbs intervals with only those tractors achieving a full pull at the previous weight being allowed to compete at the new weight.

8. Each group is given two minutes to attach their tractor and complete their pull.
9. Once the tractor starts, the pull is over if:
 - a. The tractor stops at any point (it’s not allowed to restart)
 - b. Any part of the tractor/sled completely crosses the side boundaries
 - c. Anyone makes contact with the tractor/sled
10. If there is a malfunction in the sled (a weight falls off, etc.) the group may be given another pull at the discretion of the teacher.
11. If the weight box moves all the way to the top of the sled, this is a full pull and the tractor moves onto the next round. If the tractor stops or goes outside of the lane before the weight box moves to the top of the sled, then this is a partial pull.

The distance from the starting point straight forward to the furthest distance the hitch moved should be recorded (not the length of the path the tractor and sled took).
12. All full pulls move to the next round where additional weight is added and the process is repeated until only 1 or 0 tractors make a full pull.
13. Ranking:
 - a. 1st place – heaviest full pull. If no full pulls, then
 - b. 1st place – furthest pull at heaviest weight
 - c. 2nd–Xth place – the remaining pulls at the heaviest weight in order of longest distance
 - d. Xth–Yth place – all the pulls at the next heaviest weight in order of longest distance, repeat as necessary

Lesson Five – Tractor Pull!

REVIEW: Results of the Tractor Pull

5 minutes

Participants review and modify the results to see if they're consistent with scientific principles.

Materials:

- Tractor pull scores
- *Your Tractor Setup* worksheet

Facilitation Steps:

1. Show tractor pull scores.
2. Ask each group (in order of placing) to describe their tractor setup.
3. Ask participants to complete question 2 on the *Your Tractor Setup* worksheet.