Physics of the Tractor Pull Curriculum

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About the Author

Richard Lahti, Ed.D., graduated as part of Michigan State Universitiy’s fifth year program, with certification in chemistry and physics. He later went on to complete coursework for math certification, a master’s in science education (Montana State University), and a doctorate in curriculum and instruction (University of Montana).

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.

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. *Weight and Friction* slide presentation (slides 2-13) 2. *Weight and Friction* worksheet 3. *Weight and Friction* – Answer Key	1. Print/photocopy *Weight and Friction* worksheet (one per participant) 2. Prepare *Weight and Friction* slide presentation for viewing (slides 2-13)	40 minutes
REVIEW	1. *Weight and Friction* slide presentation (slide 14)	1. Prepare *Weight and Friction* slide presentation for viewing (slide 14) 2. Ensure that partcipants still have access to their *C.E.R. Framework* worksheet, *C.E.R. Summary* worksheet, and *Divide and Conquer* – Data Table from lesson two	10 minutes

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 w*orksheet 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 Fg) pulling down over the tires, the bigger the FN (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/s *(the acceleration due to gravity, or g).*

Or W = m x g. W = 5 kg x 9.8 m/s/s = 49 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).

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.