Workshop:

Physics Invention Tasks

University of Bridgeport

Helmsley STEM Education Program

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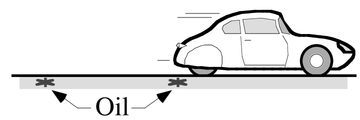
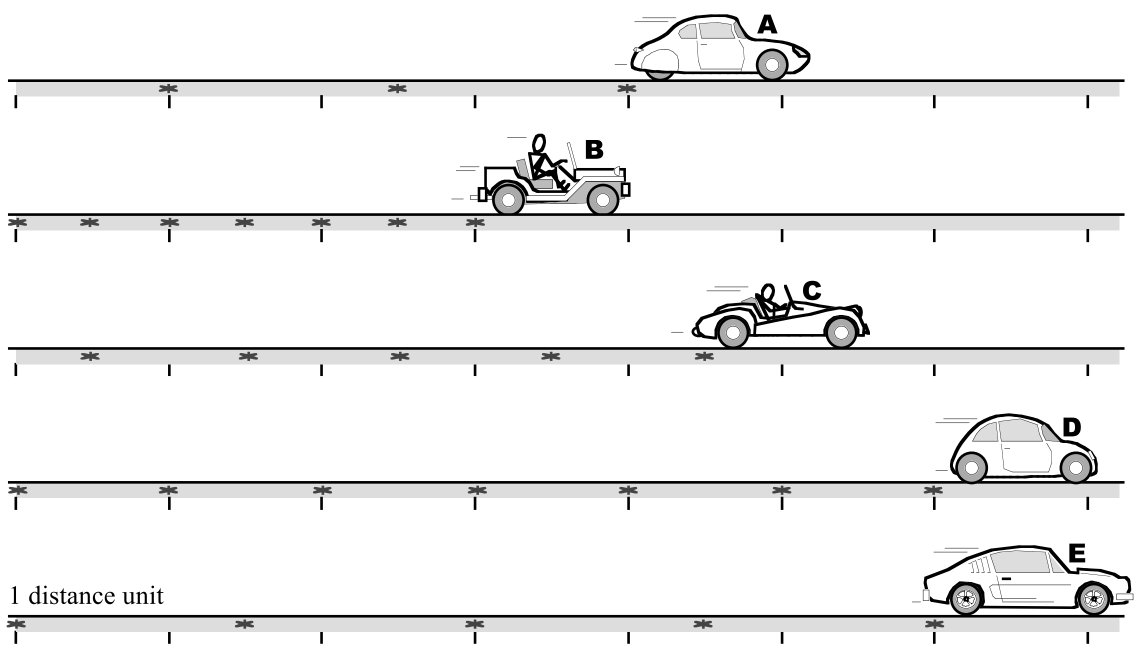
Invention Sequence 1: *Fastness* and *Speeding up*

Your task in this activity is to collaborate with your partners to invent a *fastness index* for moving cars. Below you see several cars. Come up with one number to stand for each car's "fastness." There is no watch or clock to tell you how long each car has been traveling. However, each car is dripping oil at a steady rate (i.e., all at the same rate).



Some "ground rules" for your work, and other relevant information:

- Construct your index so that a bigger number corresponds to more fastness.
- Cars made by the same company all have the same fastness.
- You have to decide which cars are from the same company. They may look different!



Follow up questions:

1. Another company (ACME) has an index of 2.5. Describe in everyday language the specific information that the number 2.5 tells about ACME cars.

2. Suppose that a friend of yours is having trouble deciding whether to compute the index for Car A as 3/2 = 1.5, or 2/3 = 0.67. Describe one way of convincing your friend of the correct answer.

Now you will invent a *speeding up index* for cars with dripping oil. Create a number to stand for each car's *speeding up*-ness. *(See the diagram on the following page.)* As before, the cars all drip oil at the same steady rate. The speedometer reading tells you how fast the car is going when the oil drips.

Some relevant information:

- A company always makes its cars speed up in the same way.
- We will not tell you how many companies there are.
- You have to decide which cars are from the same company. They may look different!

Follow up questions (Complete after inventing your speeding up index)

1. How many car companies are there? Which of the following are valid explanations for how we know that some of the cars are from the same company? Explain.

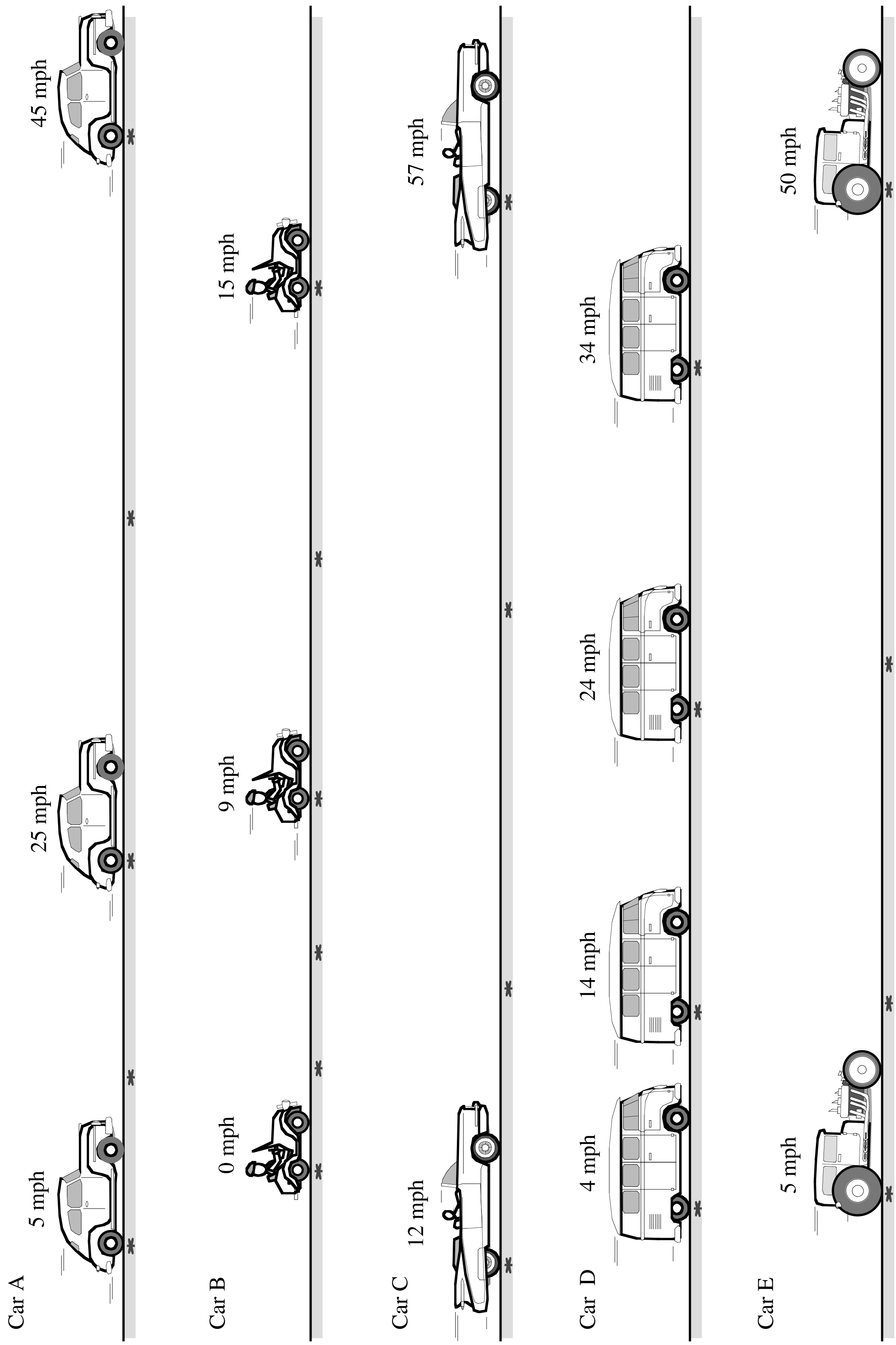
   "Some cars went as fast as others in unit of time."

   "Some cars sped up as much as others in each unit of time."

   "Some cars sped up as much as others during the entire trip shown."

2. Explain the difference between *fast*, *slow*, *speeding up quickly*, and *speeding up slowly*. Can a car be moving fast and speeding up slowly? Can a car move slow and speed up fast?

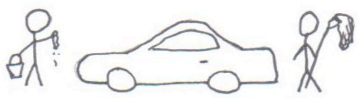
3. *Challenge question (if you have time):* Instead of *fastness,* could you invent a *slowness index* for moving cars? In other words, the bigger the number, the slower the car? Describe in everyday language the specific information that the index value tells about a car.


Car A
5 mph
25 mph
45 mph
Car B
0 mph
9 mph
15 mph
Car C
12 mph
57 mph
Car D
4 mph
14 mph
24 mph
34 mph
Car E
5 mph
50 mph

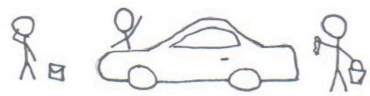
Invention Sequence 2: *Car Washing* and *Cart Mojo*

You're the manager of a chain of four car washes in which teams of employees wash the cars by hand. You want to find out which locations are the most inefficient so that the teams there can be retrained. The teams don't all have the same number of people, however, so how can you determine which location is the most inefficient?

Shown below are times for how long it took to wash a Tesla Model S. You have data for two different teams from each of the four locations. Invent a procedure for computing a *car washing inefficiency index*. Bigger index values should correspond to more inefficient teams. Teams from the same location should have the same index value.



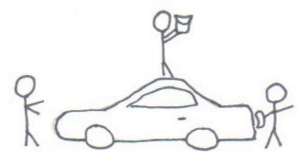
Wash Time: 10.2 minutes



Wash Time: 6.8 minutes

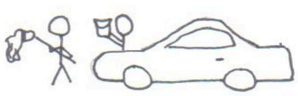
Shimmy Shine

Wash Time: 9 minutes

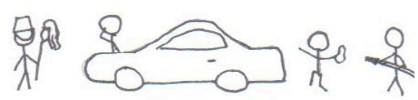


Wash Time: 12 minutes

Suds R Us

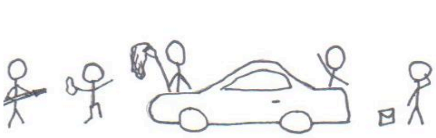


Wash Time: 11.8 minutes



Wash Time: 5.9 minutes

Klean Whips



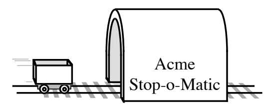
Wash Time: 8.4 minutes

Wash Time: 10.5 minutes

Sooper Sponges

Follow up question: Can you come up with an interpretation of your index? In other words, beyond providing a means for ranking, what specific information does the index value tell you about a team? (Try to come up with more than one interpretation!)

During your work at ACME, you develop a device that stops incoming carts by exerting a fixed amount of opposing force in a burst that lasts a specific amount of time. The Stop-o-Matic has two different settings, LOW and HIGH, which correspond to shorter and longer bursts of the stopping force.



In the experiments summarized in the tables below, the Stop-o-Matic brings each cart to a full stop. Together with your partners, invent a *Cart Mojo Index* (CMI) for each experiment 1-4 to characterize the amount of "movement-umpf", or "Mojo," the cart had before entering the Stop-o-Matic.

Remember: (1) a given Stop-o-Matic setting takes away the same amount of Mojo from every cart that passes through it, and (2) a bigger index should correspond to more "movement-umpf."

Stop-o-Matic LOW setting			
Exp #	Cart mass	Initial cart speed	***CMI***
1	2 kg	5 m/s	
2	2.5 kg	4 m/s	

Stop-o-Matic HIGH setting			
Exp #	Cart mass	Initial cart speed	***CMI***
3	1 kg	12 m/s	
4	4 kg	3 m/s	

Follow-up questions:

1. What are the units of your index?

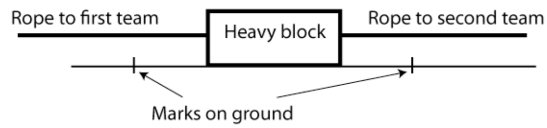
2. On HIGH, what's the max initial speed of a 1.5 kg cart the Stop-o-Matic could bring to rest?

3. Suppose Stop-o-Matic has a "VERY LOW" setting (CMI = 3). Give an example of a cart mass and initial speed that would barely be stopped at this setting.

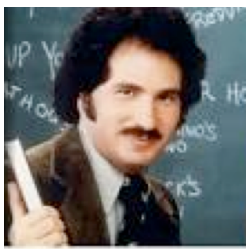
4. Suppose the Stop-o-Matic is set to VERY LOW (see question 3 above) and that the cart from Exp 1 is sent into Stop-o-Matic with speed 12 m/s. The cart slows down but doesn't stop. How fast would Cart 1 be moving when it leaves the Stop-o-Matic?

Invention Sequence: 3 *Tug o' War Index*

Your school has a fundraiser in which teachers compete in tug o' war. In a match-up, two teams are on opposite sides of a heavy block. The team that pulls the block across their mark first wins. The ground has been covered with axle grease, so that friction between the ground and the block is negligible.



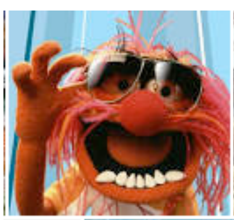
This year eight teachers are participating. Match-ups can be 1-on-1, 2-on-2, 3-on-2, etc., and spectators get a prize for picking which matchups will be over the quickest and which team will win. Because you have insider information about how hard each teacher can pull (shown below in "pulling units"), you decide to enter.


Social Studies teacher, 40 PU

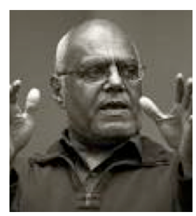

Shop teacher, 52 PU


Librarian, 19 PU

PE Teacher, 80 PU


Music teacher, 20 PU


Math teacher, 41 PU


Physics teacher, 37 PU


Principal, 100 PU

You decide to create a *tug o'war index* for each matchup to predict which side would win. Index values with greater magnitude correspond to a quicker victory for the winning team.

Matchup	Team A	Team B	*Index*
1	PE	Social Studies	
2	Social Studies	Music	
3	Social studies, Music, Principal	PE, Librarian, Math	
4	Social Studies, Music, PE, Shop	Physics, Librarian, Math, Principal	

Follow up questions:

1. Rank Matchups 1-4 according to duration, from long to short..

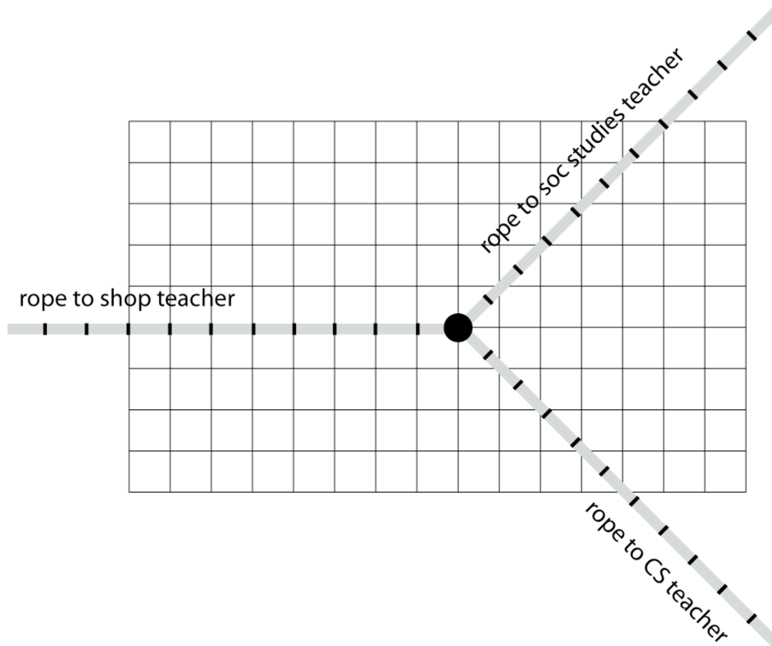
2. Write an equation for the *tug o'war index* for any two opposing teams that include P_1, P_2, P_3 on Team A and P_4 and P_5 on Team B. What does the *sign* of the index tell you?

The shop teacher challenges the social studies teacher to create a team and try to beat her. The social studies teacher thinks that if the second person on his team has her own rope, they might be more effective. He asks the computer science teacher (also 40 PU) for help. The **top view** diagram below shows the ropes. The block is represented as a dot.

1. The *direction* of each pull is along its own rope. Invent a way to represent the *strength* of each pull on the diagram. *(Hint: How can you use the "stripes" on the ropes?)*

2. Use your representation to estimate the tug o' war index for this contest. *(Note that the spacing of the stripes on the rope corresponds to the grid spacing.)*

3. Will the block start to move? If so, in what direction?



4. Do you think that the social studies teacher's idea was a good one? Please provide a brief explanation that uses plain language but also involves numbers.

Resources

Physics Invention Tasks website: http://inventiontasks.physics.rutgers.edu/

For more on Inventing with Contrasting Cases
"It's a Homerun! Using mathematical discourse to support the learning of statistics,"
Kathy Himmelberger and Daniel L. Schwartz, *Math. Teach.* 101(4), Nov. 2007, pg. 250.
This is a short, easy to read article that provides a nice illustration of how a specific invention task is used in a high school classroom setting. Available electronically at:
http://aaalab.stanford.edu/papers/Its_a_homerun_Statistics_discourse%5B1%5D.pdf

"Practicing versus inventing with contrasting cases: The effects of telling first on learning and transfer."
Daniel L. Schwartz, Catherine C. Chase, Marilyn A. Appesso, and Doris B. Chin, *J. Ed. Psych.,* 103(4), Nov 2011, pp. 759-775. Available electronically at:
http://aaalab.stanford.edu/papers/DBChin_PracticingvsInventing_JEP5_FINAL_20110720.pdf

"A time for telling," Daniel Schwartz and John Bransford, *Cog. Instr*., 16 (4), 475 (1998).
This article is long, but good; a classic.

For an extended list of references on invention instruction, see: http://aaalab.stanford.edu

For more on students' proportional reasoning:
A. Arons, "Cultivating the capacity for formal reasoning," Am. J. Phys. **44**, 834, (1976).

M. A. Simon & G. W. Blume, "Mathematical modeling as a component of understanding ratio-as-measure: A study of prospective elementary teachers," The Journal of Mathematical Behavior, Volume 13, Issue 2, Pages 183-197, (1994).

P. W. Thompson, and L. Saldanha, "Fractions and multiplicative reasoning." In J. Kilpatrick, G. Martin & D. Schifter (Eds.), *Research companion to the Principles and Standards for School Mathematics* (pp. 95-114). Reston, VA: National Council of Teachers of Mathematics, (2003).

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