Teaching Technical Feasibility with Introductory Physics: The Hyperloop Module

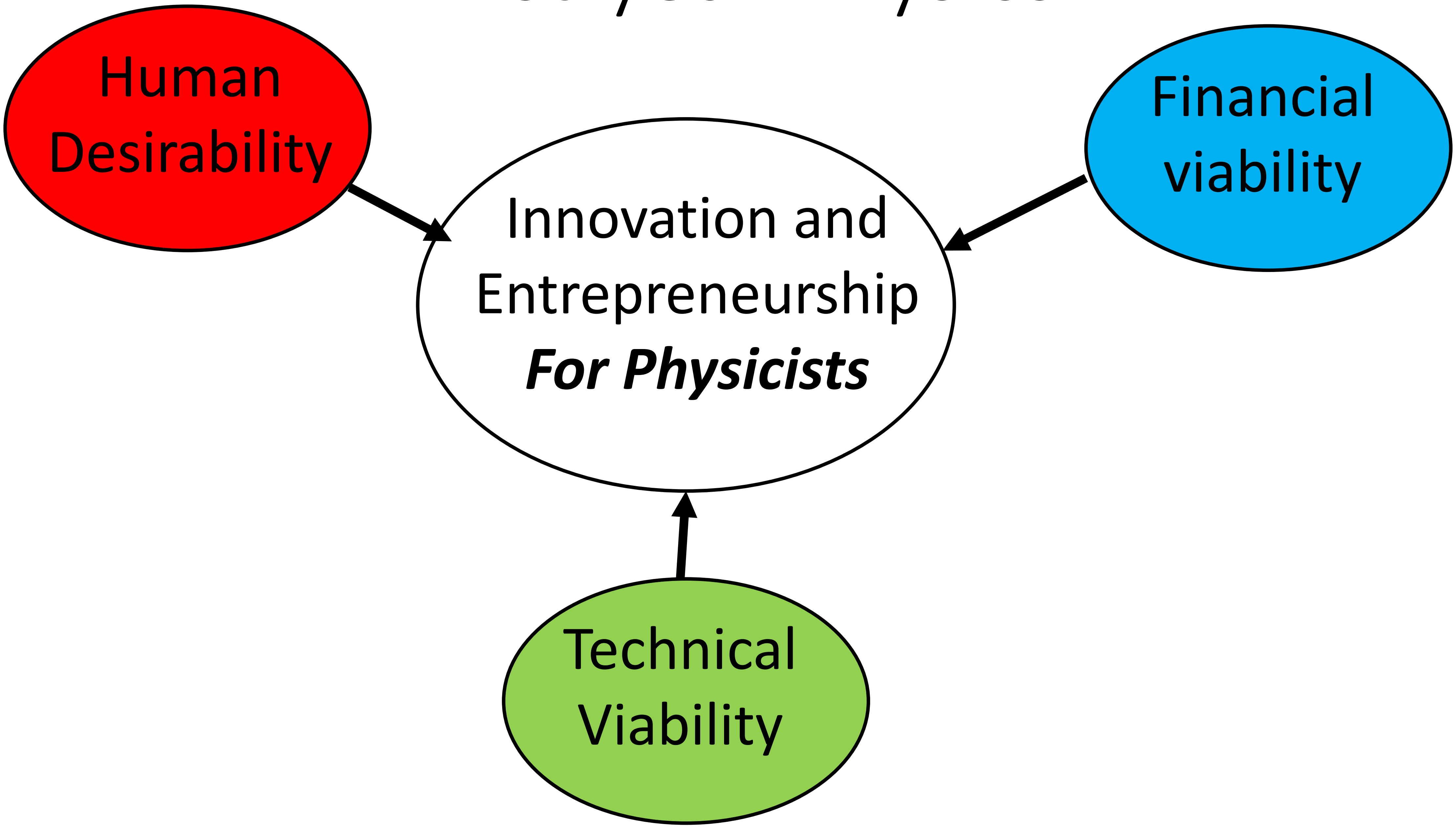
Randall Jones, Bahram Roughani
Physics Department, Loyola University Maryland

Welcome – we'll get started soon

- Dial in or use your computer's microphone and speakers.
- Submit questions via the Questions panel on the right.
- This session is being recorded.
- The recording will be sent to you via a follow up email.

Make sure to sign up to receive information about future APS webinars:
www.aps.org/careers/guidance/webinars

First-year Physics



Week 1: Constant Speed

The Hyperloop is a futuristic transportation system consisting of pods that would be able to travel at 760 miles per hour by magnetic levitation on tracks through a tube in which the air has been evacuated.

https://vimeo.com/72792529

https://vimeo.com/166185934

a. How long would it take to travel from Boston to Washington DC at a speed of 760 mi/hr? (The distance from Boston to Washington is approximately 630 km)

Week 1: Constant Speed

The Hyperloop is a futuristic transportation system consisting of pods that would be able to travel at 760 miles per hour by magnetic levitation on tracks through a tube in which the air has been evacuated.

a. How long would it take to travel from Boston to Washington DC at that speed? (The distance from Boston to Washington is approximately 630 km)

$$x = v * t$$

$$x = 630 \text{ km} = 630{,}000 \text{ m}$$

$$v = 760 \frac{\text{miles}}{\text{hour}} * \frac{1609.34 \text{ m}}{\text{mile}} * \frac{\text{hour}}{3600 \text{ s}} = 340 \text{ m/s}$$

Unit Conversions!

The total time it would take to travel from Boston to DC would be

$$t = \frac{x}{v} = \frac{630{,}000 \text{ m}}{340 \frac{\text{m}}{\text{s}}} = 1850 \text{ s} * \frac{\text{min}}{60 \text{ s}} = 30.9 \text{ minutes}$$

!!

Week 1: Constant Speed

The Hyperloop is a futuristic transportation system consisting of pods that would be able to travel at 760 miles per hour by magnetic levitation on tracks through a tube in which the air has been evacuated.

a. How long would it take to travel from Boston to Washington DC at that speed? (The distance from Boston to Washington is approximately 630 km)

   30.9 minutes

   The pod must, of course, start from rest and will require some time to reach its maximum speed and then must slow down at the end of the trip.

   How can we determine the amount of time this will this add to the trip?

   "Acceleration" - Next Week!

Week 2: Constant Acceleration

The Hyperloop is a futuristic transportation system consisting of pods that would be able to travel at 760 miles per hour by magnetic levitation on tracks through a tube in which the air has been evacuated.

a. How long would it take to travel from Boston to Washington DC at that speed? (The distance from Boston to Washington is approximately 630 km)

30.9 minutes

b. The pod must, of course, start from rest and accelerate up to its maximum speed and then decelerate to rest at the end of the trip. Assuming a "comfortable" acceleration, how much time would this add to the trip?

Human Desirability Question:

What is a "comfortable" acceleration?

Web search; Calculation, Jet plane takeoff…

$a \approx 1.5\ \mathrm{m/s^2}$

Week 2: Constant Acceleration

b. The pod must, of course, start from rest and accelerate up to its maximum speed and then decelerate to rest at the end of the trip. Assuming a "comfortable" acceleration of 1.5 m/s^2 (approximately the acceleration of a jet plane on the runway), how much time would this add to the trip?

The time it takes for the train to accelerate to a velocity of 340 m/s and the distance it travels during this time can be determined using the constant acceleration equations:

$$v = v_0 + at \qquad x = v_0 t + \frac{1}{2}at^2$$

The initial numerical values are $v = 340\,;\;\; v_0 = 0;\;\; a = 1.5\,\frac{m}{s}$

The time is thus

$$t = \frac{v}{a} = \frac{340\ \mathrm{m/s}}{1.5\ \mathrm{m/s}^2} = 227\ \mathrm{s} * \frac{1\mathrm{min}}{60\ \mathrm{s}} = 3.78\ \mathrm{min}$$

The distance travelled while the train is accelerating is determined using

$$x = \frac{1}{2}at^2 = \frac{1}{2}\left(1.5\ \mathrm{m/s}^2\right)(227\ \mathrm{s})^2 = 38{,}600\ \mathrm{m} = 38.6\ \mathrm{km}$$

The distance and time required to stop are the same as the distance and time required to start, so the distance that the train operates at a constant velocity of 340 m/s is

$$630{,}000\ \mathrm{m} - 2(38{,}600\ \mathrm{m}) = 553{,}000\ \mathrm{m}$$

and the amount of time it takes to travel this distance at 340 m/s is

$$t = \frac{x}{v} = \frac{553{,}000\ \mathrm{m}}{340\ \mathrm{m/s}} = 1630\ \mathrm{s} = 27.2\ \mathrm{min}$$

The total duration of travel is $(27.2\ \mathrm{min}) + 2(3.78\ \mathrm{min}) = \ 34.8\ \mathrm{min}$

Which means 3.9 minutes is added to the travel time due to acceleration and deceleration.

Week 2: Constant Acceleration

The Hyperloop is a futuristic transportation system consisting of pods that would be able to travel at 760 miles per hour by magnetic levitation on tracks through a tube in which the air has been evacuated.

a. How long would it take to travel from Boston to Washington DC at that speed? (The distance from Boston to Washington is approximately 630 km)

   30.9 minutes

b. The pod must, of course, start from rest and accelerate up to its maximum speed and then decelerate to rest at the end of the trip. Assuming a "comfortable" acceleration of 1.5 m/s^2 (approximately the acceleration of a jet plane on the runway), how much time would this add to the trip?

   3.9 minutes is added to the travel time due to acceleration and deceleration.

Week 2: Constant Acceleration

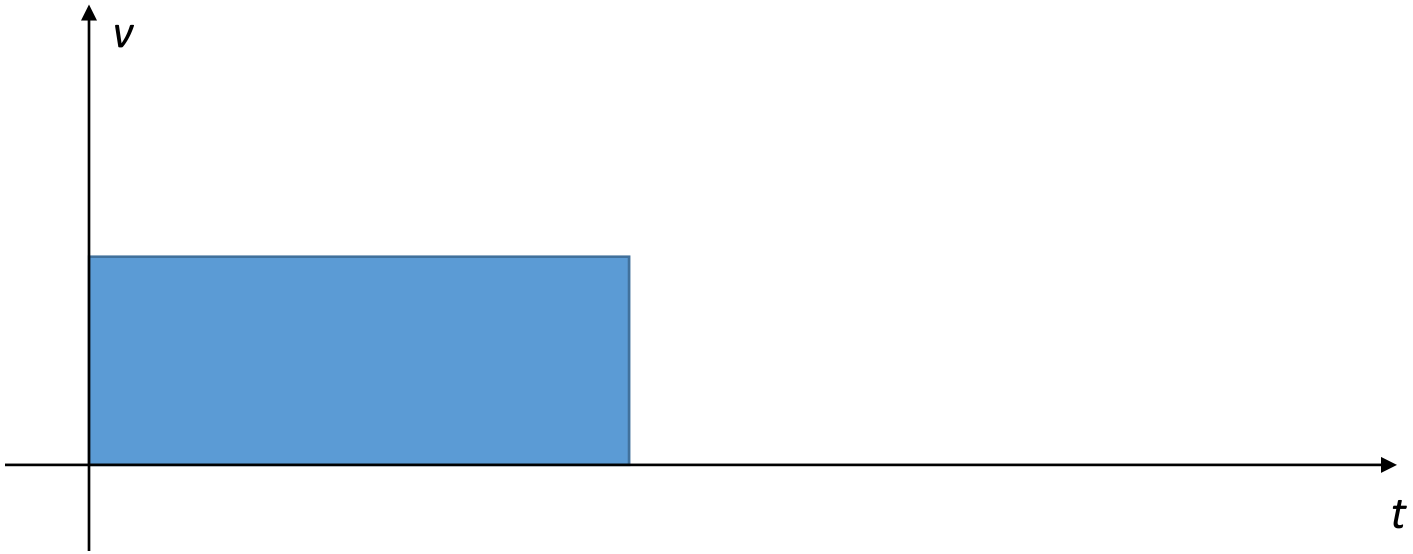
b. The pod must, of course, start from rest and accelerate up to its maximum speed and then decelerate to rest at the end of the trip. Assuming a “comfortable” acceleration of 1.5 m/s^2 (approximately the acceleration of a jet plane on the runway), how much time would this add to the trip?

Graphical Solution

Week 2: Constant Acceleration

b. The pod must, of course, start from rest and accelerate up to its maximum speed and then decelerate to rest at the end of the trip. Assuming a "comfortable" acceleration of 1.5 m/s^2 (approximately the acceleration of a jet plane on the runway), how much time would this add to the trip?

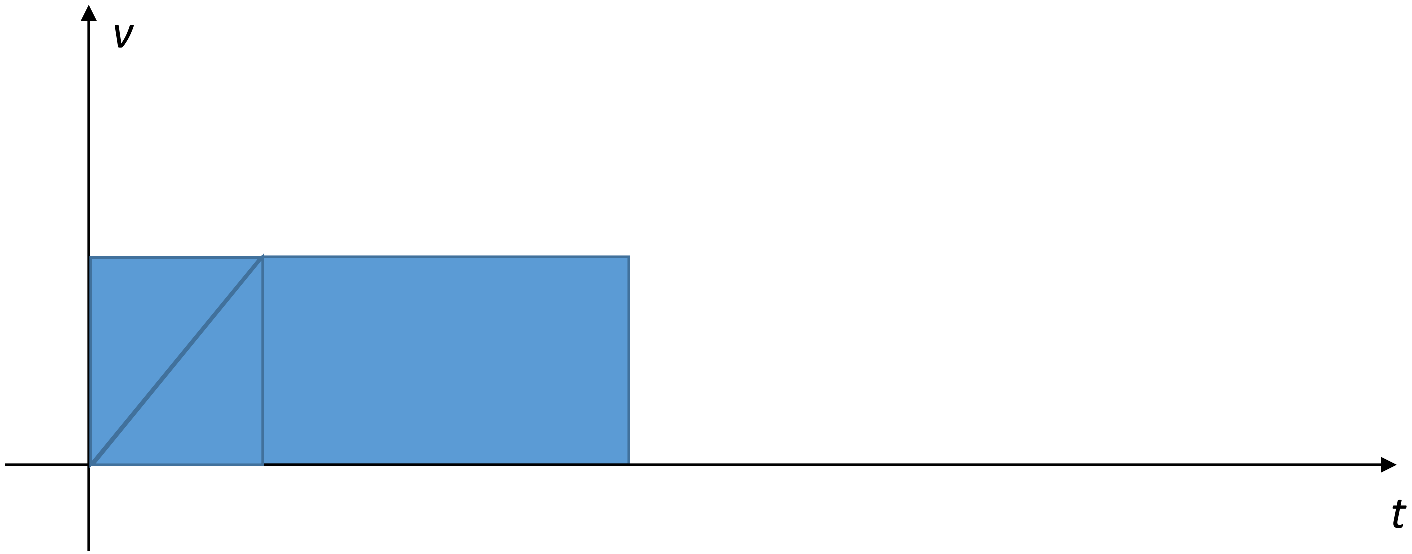
Graphical Solution



Week 2: Constant Acceleration

b. The pod must, of course, start from rest and accelerate up to its maximum speed and then decelerate to rest at the end of the trip. Assuming a "comfortable" acceleration of 1.5 m/s^2 (approximately the acceleration of a jet plane on the runway), how much time would this add to the trip?

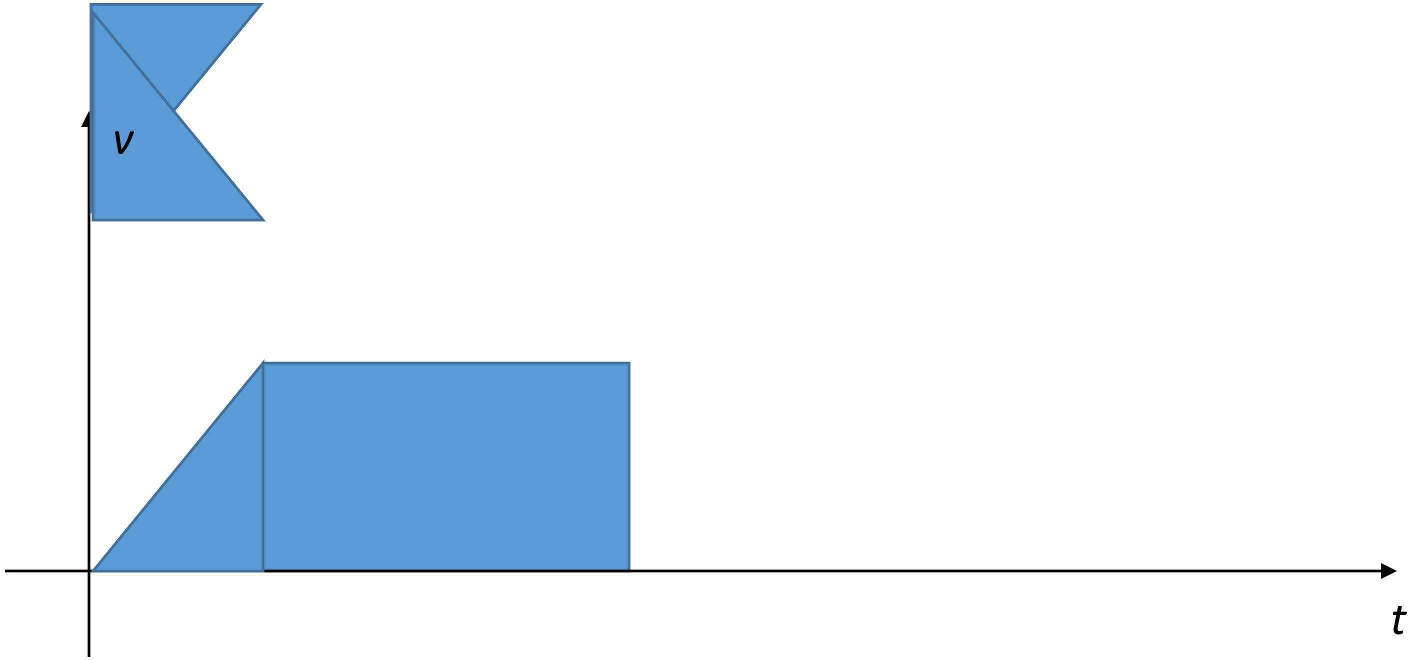
Graphical Solution



Week 2: Constant Acceleration

b. The pod must, of course, start from rest and accelerate up to its maximum speed and then decelerate to rest at the end of the trip. Assuming a "comfortable" acceleration of 1.5 m/s^2 (approximately the acceleration of a jet plane on the runway), how much time would this add to the trip?

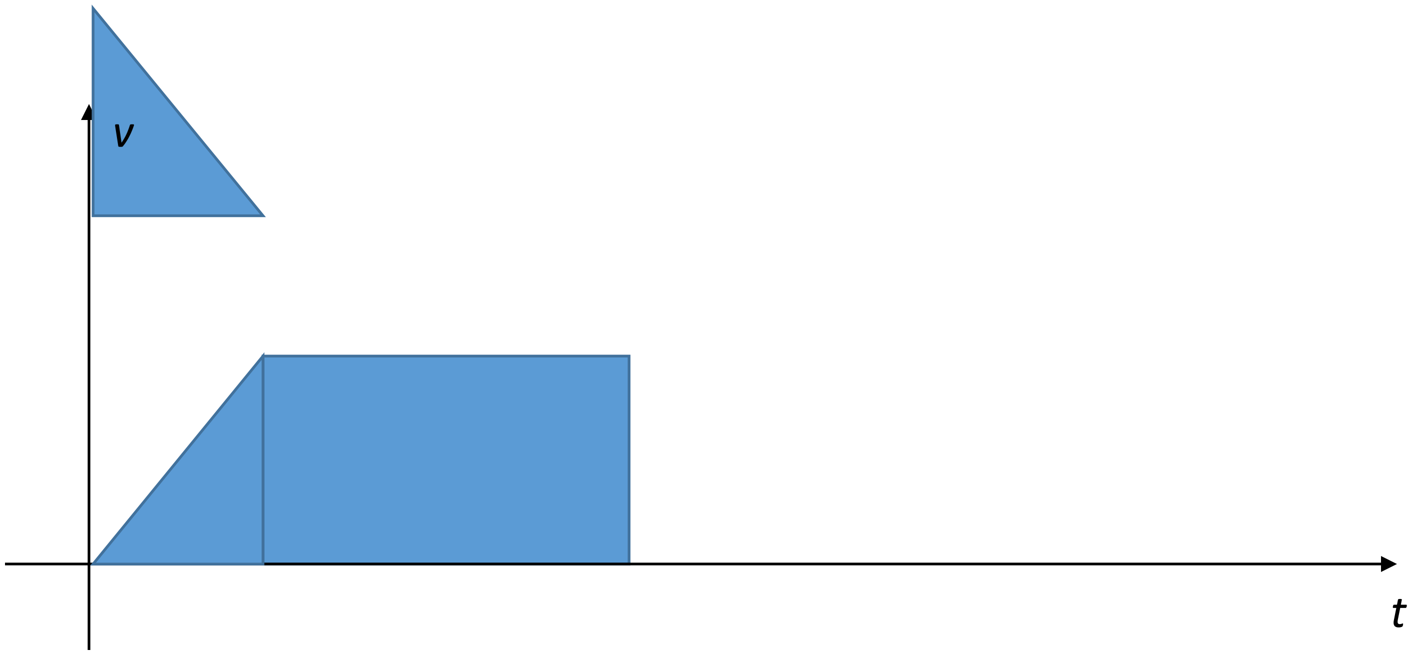
Graphical Solution



Week 2: Constant Acceleration

b. The pod must, of course, start from rest and accelerate up to its maximum speed and then decelerate to rest at the end of the trip. Assuming a "comfortable" acceleration of 1.5 m/s^2 (approximately the acceleration of a jet plane on the runway), how much time would this add to the trip?

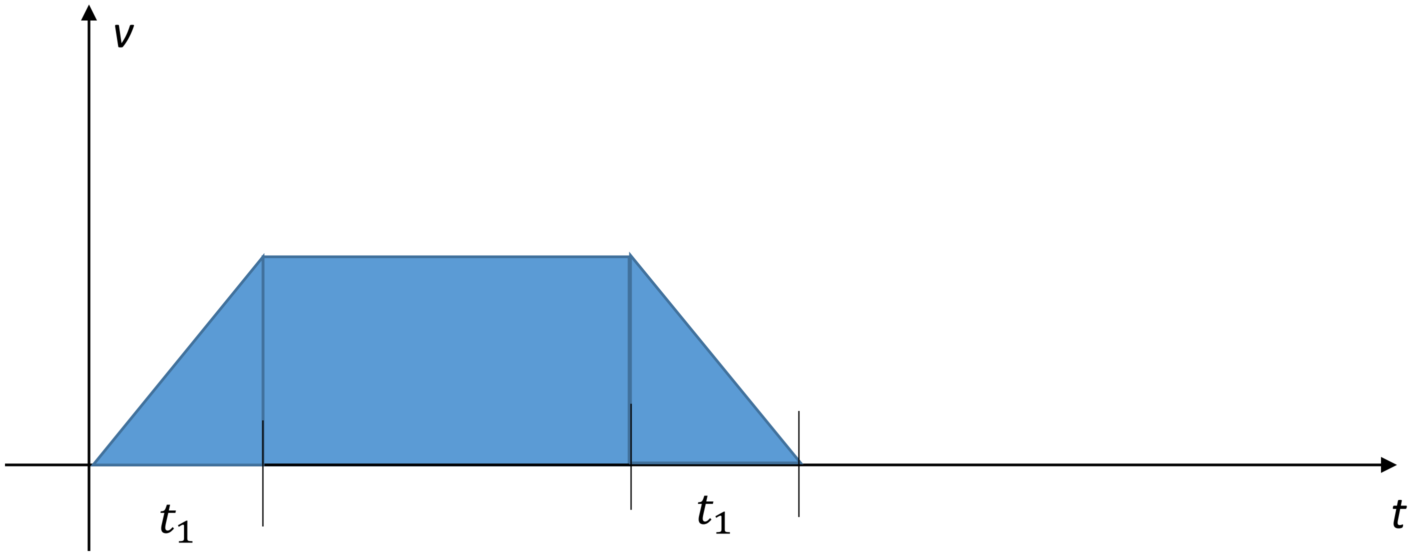
Graphical Solution



Week 2: Constant Acceleration

b. The pod must, of course, start from rest and accelerate up to its maximum speed and then decelerate to rest at the end of the trip. Assuming a "comfortable" acceleration of 1.5 m/s^2 (approximately the acceleration of a jet plane on the runway), how much time would this add to the trip?

Graphical Solution



Additional time: $t_1 = v_{\max}/a$

Week 2: Constant Acceleration

b. The pod must, of course, start from rest and accelerate up to its maximum speed and then decelerate to rest at the end of the trip. Assuming a "comfortable" acceleration of 1.5 m/s^2 (approximately the acceleration of a jet plane on the runway), how much time would this add to the trip?

The time it takes for the train to accelerate to a velocity of 340 m/s and the distance it travels during this time can be determined using the constant acceleration equations:

$$v = v_0 + at \qquad x = v_0 t + \frac{1}{2}at^2$$

The initial numerical values are $v = 340\,;\ \ v_0 = 0;\ \ a = 1.5\frac{m}{s}$

The time is thus

$$t = \frac{v}{a} = \frac{340\ \mathrm{m/s}}{1.5\ \mathrm{m/s^2}} = 227\ \mathrm{s} * \frac{1\mathrm{min}}{60\ \mathrm{s}} = 3.78\ \mathrm{min}$$

The distance travelled while the train is accelerating is determined using

$$x = \frac{1}{2}at^2 = \frac{1}{2}\left(1.5\ \mathrm{m/s^2}\right)(227\ \mathrm{s})^2 = 38{,}600\ \mathrm{m} = 38.6\ \mathrm{km}$$

The distance and time required to stop are the same as the distance and time required to start so, the distance that the train operates at a constant velocity of 340 m/s is

$$630{,}000\ \mathrm{m} - 2(38{,}600\ \mathrm{m}) = 553{,}000\ \mathrm{m}$$

and the amount of time it takes to travel this distance at 340 m/s is

$$t = \frac{x}{v} = \frac{553{,}000\ \mathrm{m}}{340\ \mathrm{m/s}} = 1630\ \mathrm{s} = 27.2\ \mathrm{min}$$

The total duration of travel is $(27.2\ \mathrm{min}) + 2(3.78\ \mathrm{min}) =\ 34.8\ \mathrm{min}$

Which means 3.9 minutes is added to the travel time due to acceleration and deceleration.

Week 2: Constant Acceleration

b. The pod must, of course, start from rest and accelerate up to its maximum speed and then decelerate to rest at the end of the trip. Assuming a "comfortable" acceleration of 1.5 m/s^2 (approximately the acceleration of a jet plane on the runway), how much time would this add to the trip?

The time, t_0, to travel the total distance, *d,* if the train traveled at a constant speed, $v_{\max}$, is

$$t_0 = \frac{d}{v_{\max}}$$

The time to reach maximum speed if accelerating from rest is

$$t_1 = \frac{v_{\max}}{a}$$

The distance travelled while the train is accelerating is

$$x_1 = \frac{1}{2}at_1^2 = \frac{1}{2}a(v_{\max}/a)^2 = \frac{1}{2}v_{\max}^2/a$$

The distance and time required to stop are the same as the distance and time required to start so, the distance, x_2, that the train operates at its maximum velocity is

$$x_2 = d - 2x_1 = d - v_{\max}^2/a$$

and the amount of time it takes to travel this distance is

$$t_2 = \frac{x_2}{v_{\max}} = \frac{d}{v_{\max}} - \frac{v_{\max}}{a} = t_0 - t_1$$

The total duration of travel is t_1 to get up to speed, t_2 at constant speed and t_1 to come to a stop. Or

$$t_2 + 2t_1 = t_0 + t_1$$

Which means the added time is just $t_1 = v_{\max}/a$.

Week 2: Constant Acceleration

The Hyperloop is a futuristic transportation system consisting of pods that would be able to travel at 760 miles per hour by magnetic levitation on tracks through a tube in which the air has been evacuated.

a. How long would it take to travel from Boston to Washington DC at that speed? (The distance from Boston Washington is approximately 630 km)

   30.9 minutes

b. The pod must, of course, start from rest and accelerate up to its maximum speed and then decelerate to rest at the end of the trip. Assuming a "comfortable" acceleration of 1.5 m/s^2 (approximately the acceleration of a jet plane on the runway), how much time would this add to the trip?

   3.78 minutes is added to the travel time due to acceleration and deceleration.

Week 2: Constant Acceleration

The Hyperloop is a futuristic transportation system consisting of pods that would be able to travel at 760 miles per hour by magnetic levitation on tracks through a tube in which the air has been evacuated.

a. How long would it take to travel from Boston to Washington DC at that speed? (The distance from Boston to Washington is approximately 630 km)

   30.9 minutes

b. The pod must, of course, start from rest and accelerate up to its maximum speed and then decelerate to rest at the end of the trip. Assuming a "comfortable" acceleration of 1.5 m/s^2 (approximately the acceleration of a jet plane on the runway), how much time would this add to the trip?

   3.78 minutes is added to the travel time due to acceleration and deceleration.

c. Assume the Hyperloop makes 4 evenly spaced stops in traveling between Boston and Washington, DC and waits at each station for 5 minutes to allow passengers to disembark and to board. How much time would be added to your answer to part b? Note that 4 stops means the distance is divided into 5 equal-length segments.

Week 2: Constant Acceleration

c. Assume the Hyperloop makes 4 evenly spaced stops in traveling between Boston and Washington, DC and waits at each station for 5 minutes to allow passengers to disembark and to board. How much time would be added to your answer to part b? Note that 4 stops means the distance is divided into 5 equal-length segments.

The distance between each stop is

$$630 \text{ km} * \frac{1}{5} = 126 \text{ km}$$

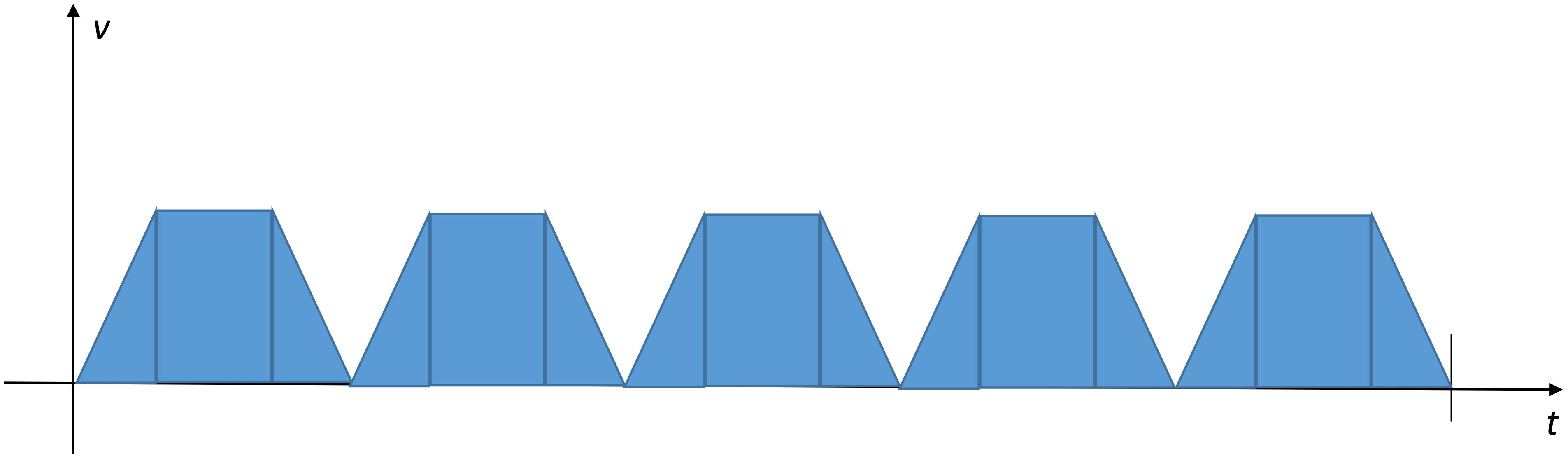
The Hyperloop requires $2(38.6 \text{ km}) = 77.2 \text{ km}$ in total for deceleration and acceleration at each stop, which is viable if the stops are 126 km apart. The amount of time added to the trip with 4 stops would be

$$4(5 + 3.78) = 35.1 \text{ min}$$

Adding these stops would more than double the amount of time it takes to travel between Boston and Washington D.C.

Week 2: Constant Acceleration

c. Assume the Hyperloop makes 4 evenly spaced stops in traveling between Boston and Washington, DC and waits at each station for 5 minutes to allow passengers to disembark and to board. How much time would be added to your answer to part b? Note that 4 stops means the distance is divided into 5 equal-length segments.



Week 2: Constant Acceleration

The Hyperloop is a futuristic transportation system consisting of pods that would be able to travel at 760 miles per hour by magnetic levitation on tracks through a tube in which the air has been evacuated.

a. How long would it take to travel from Boston to Washington DC at that speed? (The distance from Boston to Washington is approximately 630 km)

   30.9 minutes

b. The pod must, of course, start from rest and accelerate up to its maximum speed and then decelerate to rest at the end of the trip. Assuming a "comfortable" acceleration of 1.5 m/s^2 (approximately the acceleration of a jet plane on the runway), how much time would this add to the trip?

   3.9 minutes added to the travel time due to acceleration and deceleration.

c. Assume the Hyperloop makes 4 evenly spaced stops in traveling between Boston and Washington, DC and waits at each station for 5 minutes to allow passengers to disembark and to board. How much time would be added to your answer to part b? Note that 4 stops means the distance is divided into 5 equal-length segments.

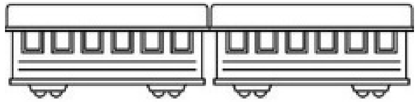
   35.6 minutes added to the total travel time

d. Does your answer to part (c) make this concept less attractive? What modifications might you consider to make this more feasible?. This is an issue of "Human Desirability."

Boarding Passengers

Loading and unloading passengers can take as much time as travelling between destinations.
Is there a way to get passengers on and off without slowing down the Hyperloop?

One Solution https://vimeo.com/25465925



Another Idea

Complications?

“Approach Loop” requires 38.6 km to get up to speed.

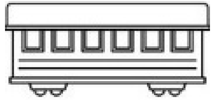
How much time (and distance) to transfer passengers?”

What happens if transfer isn’t complete when cars must separate?

Circular path complications?
wait until next week!

Detachable Cars

Detachable Cars

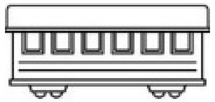


What additional complications does this add?

Additional Complications

Additional Complications

Since the last car is dropped off at the next station, passengers who wish to get off would need to move back to that car before arriving at that station. Passengers who do not wish to get off would need to move forward.



Second Example: Centripetal Acceleration

If the Hyperloop will travel between Boston and Washington, D.C., passing through New Haven, CT, New York, NY and Philadelphia, PA, it clearly cannot do this traveling in a straight line (see map). When the Hyperloop goes around a bend, there will be a centripetal acceleration. We need to ensure that this acceleration is not too large.
Using the map provided, estimate the "tightest" turn the Hyperloop will need to make to pass through each of these stations and the centripetal acceleration if the Hyperloop is traveling at 340 m/s. What do your numbers suggest about the feasibility of the Hyperloop design?

Second Example: Centripetal Acceleration

One way to draw the arcs is shown below. The arc between New Haven and New York seems to have the shortest radius of curvature. The radius length on the map is approximately 3.5 cm, so the actual radius is equal to

$$R = (3.5\text{ cm})\frac{50\text{ mi}}{2.3\text{ cm}}\frac{1610\text{ m}}{1\text{ mi}} = 1.22\times10^5\text{m}$$

The centripetal acceleration is thus

$$a_c = v^2/R = (340\text{ m/s})^2/(1.22\times10^5\text{m }) = 0.94\text{m}/s^2$$

So this seems within our acceptable value of acceleration.

If there are no tighter turns!

Additional Hyperloop Examples:

- Combination of Tangential and Centripetal Acceleration
- Air Resistance
- Work and Energy
- Momentum / Collisions
- Relativistic Time Dilation
- Compare Hyperloop speed to speed of Space Station
- Others….

Other Examples:

The $1000 Question:

Would you invest $1000 ($100?) in my company to design, build and sell … ?

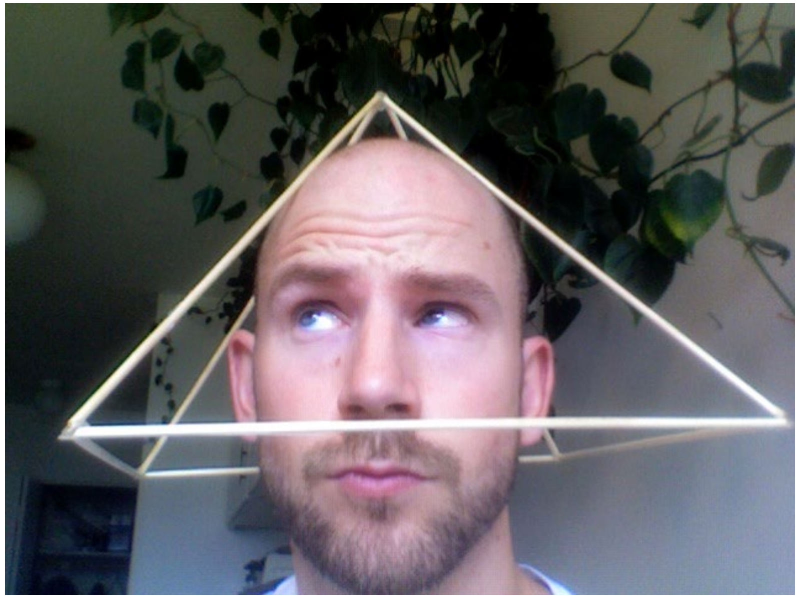
- All-terrain wheelchair
- Rooftop solar panels for a car

First consideration is *Feasibility.*

*Your p*hysics training makes you the expert!

Other interesting (?) ideas
Would you invest your money?

- Pyramid Power



Other interesting (?) ideas
Would you invest your money?

- Magnet Therapy

Other interesting ideas
Would you invest your money?

-
-
-
-

Work, Energy and Power

Problem: Approximately, what is your change in gravitational potential energy when you climb a set of stairs?

- $\Delta U_g = m\, g\, \Delta y$
  - What is your mass?
    - $m \approx 75$ kg
  - What is the height of a flight of stairs?
    - Look it up!
    - $\Delta y \approx 4$ m
- $\Delta U_g \approx (75\text{ kg})(10\text{ N/kg})(4\text{ m}) = 3000\text{ J}$

Work, Energy and Power

Problem: Approximately, how much *work* do you do when you climb a set of stairs?

- $W = \Delta U_g \approx 3000$ J

Note that you do this work on yourself.

Work, Energy and Power

Problem: Approximately, what is your power output as you (leisurely) climb a set of stairs?

- $P = W/\Delta t$

How long does it take to *leisurely* climb a set of steps?

- Go do it!
- $\Delta t \approx 15$ s. (maybe!)
- $P \approx (3000 \text{ J})/(15 \text{ s}) = 200$ W

Work, Energy and Power

Problem: Suppose you "climb" the same distance on a stair-climbing machine. Is the work you do the same?

- Seems like it *must* be.

Where does the energy go?

- Energy is "lost" to thermal energy (the room warms up).

Can you think of any ways you could use what we have just learned?

- Power output ≈ 200 Watts

Useful Applications of Human-generated Mechanical Power

Power electrical devices

- Wait until next semester – electrical energy and power
- One example: The Monstrosity Bike
  https://www.youtube.com/watch?v=klQ55wrylSg

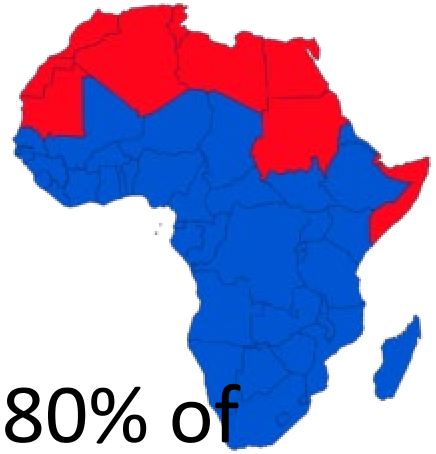
Any other needs that could be addressed?

- .
- .
- .

Useful Applications of Human-generated Mechanical Power

Sub-Saharan Africa

Where is the economy focused?



- 80% Sub-Saharan Africans are farmers
- Tanzania – half GDP from farming and 80% of employment from farming
- Uganda 85% of economic output based on farming
- **Irrigated agriculture has greatest potential impact**

Useful Applications of Human-generated Mechanical Power

Could we develop a human-powered pump for irrigation in sub-Saharan Africa?

- The thousand dollar question:
  - Would you invest $1000 in my company?
- Initially, this is a feasibility question.

Feasibility of a Human-powered Irrigation Pump

What do we need to know/assume/estimate?

- How much land (acres)?
- How much water per acre?
- How high must we lift the water?
- How long can a person operate a pump?

How do we determine these things?

- Make assumptions and/or use Google!

Feasibility of a Human-powered Irrigation Pump

How much land?

- 1 acre

How much water per acre?

- Google it!
- One approximation: 20,000 liters/day

How high must we lift the water?

- 10 m seems reasonable (from a well?)

How long can a person operate a pump?

- Two hours?

Feasibility of a Human-powered Irrigation Pump

Let’s ask: How long does it take to pump enough water to irrigate one acre?

Feasibility of a Human-powered Irrigation Pump

One liter of water has a mass of 1 kg, so the work required to raise 20,000 liters 10 meters is

$$W = mgh = (20{,}000\text{kg})(10\text{N/kg})(10\text{m})$$

$$= 2 \times 10^6 \text{ J}$$

If we do 200 J of work every second, the required time is

$$t = (2 \times 10^6 \text{ J})/(200 \text{ J/s}) = 10^4 \text{ s} = 2.8 \text{ hours}$$

So this seems feasible.

Would you invest $1000?

Practicality of a Human-powered Irrigation Pump

- Other mechanical issues:
  - Pump design
  - Friction (*efficiency*)
- Materials
  - Locally available?
  - Repairs/spare parts
- Cost
  - Can farmers afford it?
  - Can some profit be made?

Maybe you need to bring an engineer on board now for some of these questions.

Martin Fisher and Kickstart

“Poverty to Prosperity in Just One Season”

http://kickstart.org/

https://www.youtube.com/watch?v=PCPRgOGFElY

Kickstart’s Technology History: Super MoneyMaker (1998)

- Dual piston micro-Irrigation pump
- Can pump from 7m below to 7m above
- Weighs 45 pounds
- Waters 2 acres
- Efforts similar to walking
- Costs about $95

Kickstart and Martin Fisher Awards and Honors

- Martin Fisher
  - Design News Magazine's Engineer of the Year, 2008
  - $100,000 Lemelson MIT Award for Sustainability, 2008
  - OneWorld.net Person of the Year Award, 2008
- Kickstart International
  - Drucker Award for Nonprofit Innovation, 2008

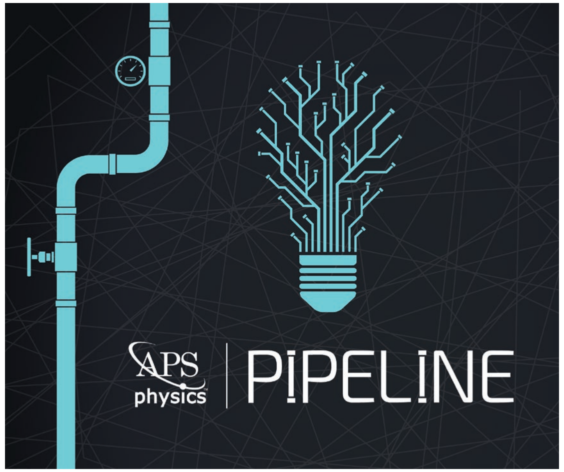
PH491/CS491/EG491
Technical Innovation and Entrepreneurship

Learn how to start with an idea and take it through to a finished, marketable product

- Idea generation / Feasibility
- Intellectual property
- Business plan
- Financing
- Marketing
- Patents

Teaching Technical Feasibility with Introductory Physics: The Hyperloop Module

To learn the latest in physics innovation and entrepreneurship education, please sign up for our monthly PIE Newsletter: go.aps.org/innovation



Make sure to sign up to receive information about future APS webinars: www.aps.org/careers/guidance/webinars