Name: ___________

Inquiry Question

We all know that great athletes are physically strong. They train very hard to improve upon their strength and conditioning. But they are also very "efficient" at what they do. What does this mean?

Top athletes in all sports work extremely hard to maintain and improve upon their strength and conditioning. However, as the competition also gets stronger they must look for other advantages. Improving their athletic efficiency is quickly becoming more and more important. The best athletes are strong, efficient, and intelligent. Let's see if we can improve on at least two of these aspects of sport…

Instructions

Using a pencil, answer the following questions. The lab is marked based on clarity of responses, completeness, neatness, and accuracy. Do your best! Please ensure that any data measured (or recorded) includes the appropriate number of significant digits (only one uncertain digit).

This activity is divided into three sections:

- **Core** – this first section explores only the basic "core" ideas involved in understanding. Students must demonstrate a sound understand with all of their answers in this section BEFORE attempting the next section.
- **Mastery** – Your instructor will NOT review this section if the Core section above shows any misconceptions. In this section students will make predictions and apply the concepts and ideas learned above. For complete mastery it is expected that data collection and scientific procedures will be as accurate as possible. All work shown should be clear with any units included. Answers should be rounded off to the correct number of significant figures based on the data collected.
- **Ace** – Once again, your instructor will only look at this section provided he/she is confident that the above Mastery criteria has been met. In this section students will demonstrate a deeper understanding of the concepts through error analysis, experimental design etc. Physics concepts from other units already covered will often be required here.

Instructions:

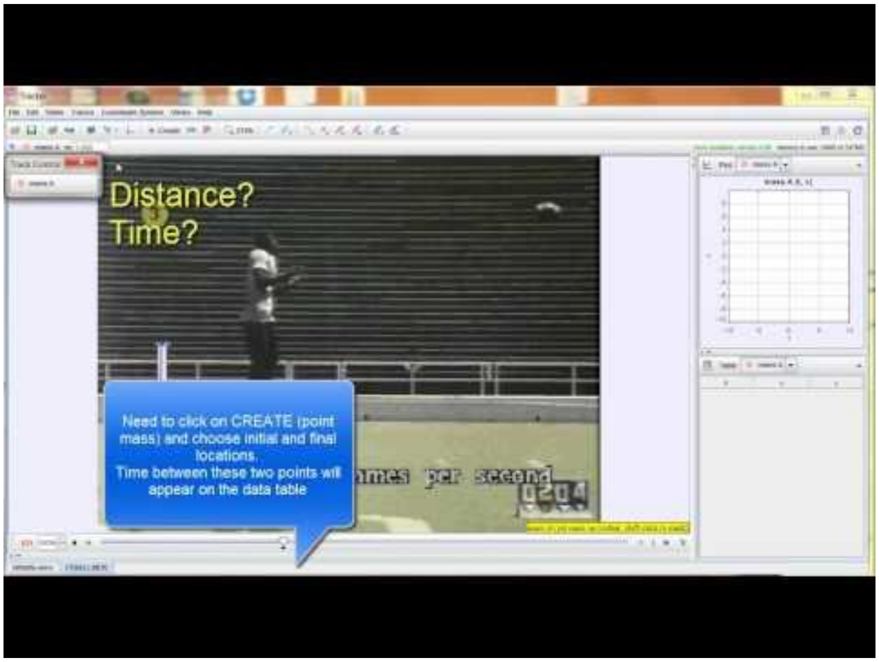
Open the pdf instructions file and download the *Tracker* software from the link below. Video tutorials on the use of Tracker are included. See Kinematics Free-Fall instructions below for additional support.

Click here for pdf Instructions

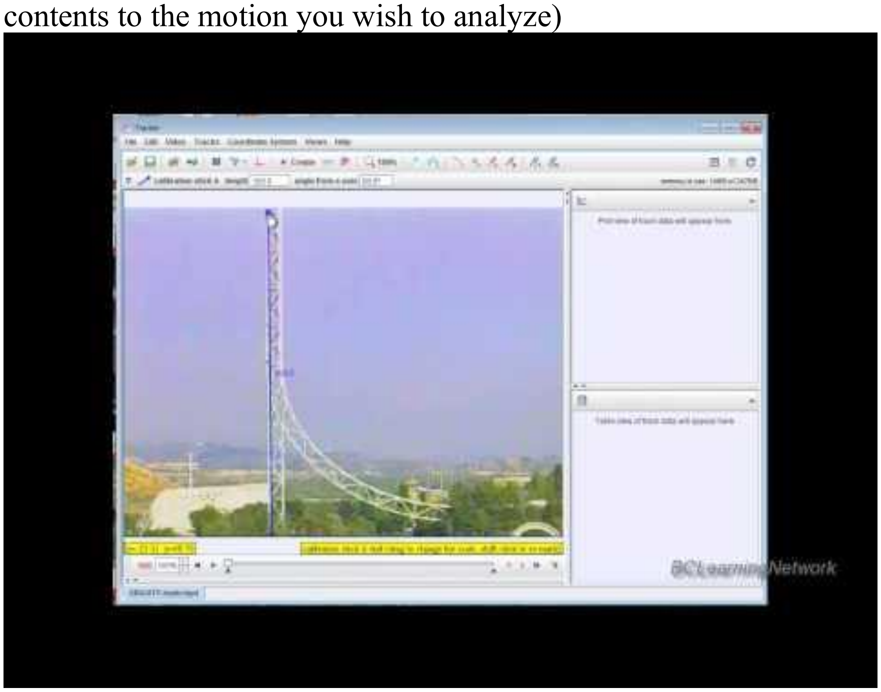
Tracker Software (click to install)

To get you started quickly we have also created **video instructions**. They have been broken down into three parts on *YouTube*. You may need the *.pdf* above as well for specific data analysis instructions. Follow the links below:

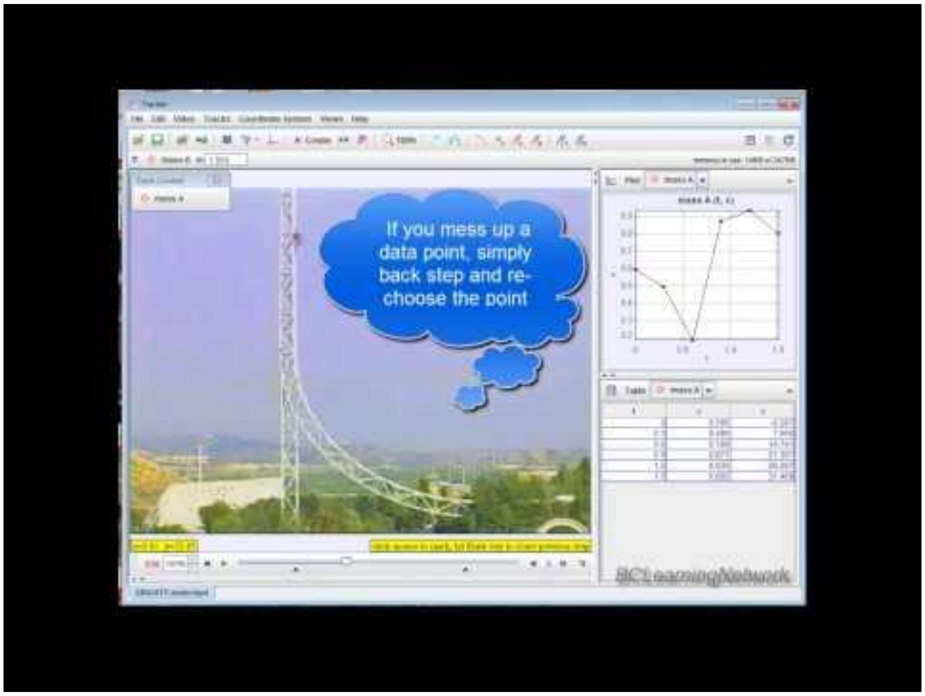
Tracker Tutorial Part 1 - For an easy way to take distance, time, and angle measurements use the Tracker software to analyze videos (or photos). Watch the video below for a quick tutorial:



Tracker Tutorial Part 2 (How to load the movie, set the scaling and origin, and crop the contents to the motion you wish to analyze)



Tracker Tutorial Part 3 (How to collect, analyze and graph data)



Your video…

Right-Click and chose *Copy Link Location* for the video showing the jump

Pole Vault Video

(right click and select copy link location, open in browser to download. Then open the download folder to view the file and change extension to .mp4 - vs. .zzz)

Here's what the sample video should look like:

https://www.youtube.com/watch?v=gcxF5L9xS84&feature=youtu.be

Refer to the *pdf lab instructions* (above)

Having successfully "TRACKED" your high jumper using the software as described in the instructions, it's now time to begin our analysis.

The scaling of the video is displayed on the left side with two, white, 1m long "scaling bars":

- Scaling Object Description: white scaling bars
- Scaling Object actual length: 1 m

Part 1: Core

Open the video entitled *PoleVault* and play it through as many times as required to answer the questions below. You may need to do a little research to assist with some of the questions.

Energy Transformations

For closed, isolated systems that include only mechanical energy (gravitational and kinetic energies) we normally state our ***Law of Conservation of Energy*** as follows:

Total mechanical energy before = Total mechanical energy after

$$E_{pi} + E_{ki} = E_{pf} + E_{kf}$$

1. Describe the mechanical energy transformations involved up until the athlete reaches the top (apex) of his jump. Be sure to discuss what type of mechanical energy is present or stored at three locations:

   i. Running down the track:

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   ii. Halfway up to the top where the pole reaches its maximum bend:

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   iii. At the maximum height:

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2. State the *Law of Conservation of Energy* in the form of a three-way equation (A = B = C) that summarizes the above in the form of a simple equation.

Law of Conservation of Energy (most basic equation where we include only E_p and E_k)
Running down the track (energy) = half way up (energy) = top (energy)
E_{ki} = ____________________ = ____________________

3. What would you need to measure to determine whether or not *mechanical energy* has been conserved for this jump? How could you prove that the athlete's initial energy is the same as the final energy at the apex of the jump?

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4. When using *Newtonian Mechanics* it is necessary to take measurements from the *centre of mass*. This will become the "spot" that you will keep track of for calculation considerations (heights and velocities should be measured from this point). Where is the centre of mass for this athlete? How does the position of his body affect its location? *Hint: Watch the video under resources to help you with this.*

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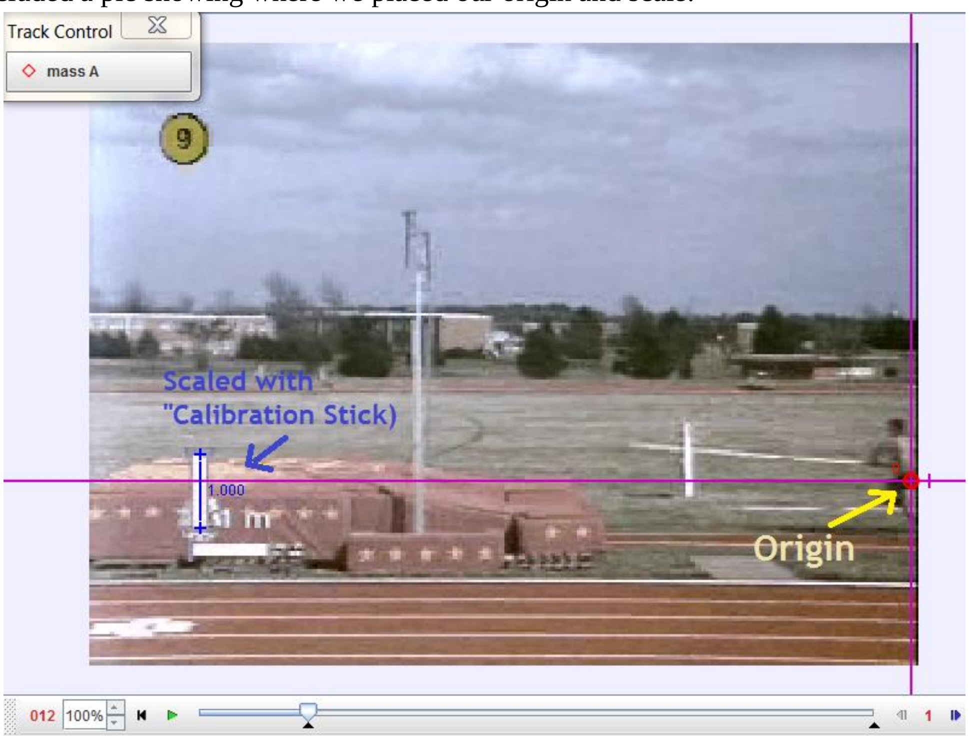
Use the tracker software to create two graphs for analysis. To analyze velocities it is recommended that you create a d_x versus t graph (x vs t on Tracker). To analyze the heights you will need to examine a d_y versus t graph (y vs t on Tracker).

Some useful tips or hints:

- Remember to take all measurements to the athletes centre of mass (be sure to watch the video for the best estimate as to where this is as he flies over the bar at the top).
- Notice that a scale is given on the bottom left of the screen showing two perpendicular metre sticks.
- Choose a good video player that will show the time as well (useful for calculating any velocities)
- Choose a good reference level from which you will measure all heights. If you choose the ground on which he runs then he will have an initial potential energy since his centre of mass is above this. Alternatively you could choose his centre of mass (as he runs) as the "ground" level and take all height measurements from here.
- Finally, you are welcome to use the *Tracker* software. Be sure to scale it with the *Calibration Stick* using the metre sticks on the video. Also, be sure to move the *origin* to where the athlete first appears on the track. Slide the origin up to your chosen "reference level" (see above). We have included a pic showing where we placed our origin and scale:



5. Review your kinematics graphs. How can you determine the velocity from a displacement versus time graph (your x versus t graph)?

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Tips: When you right-click on any graph in *Tracker* you have the option to choose *Analyze*. When selected, a new window will appear with just your graph along with some tools to help analyze slopes. • If you click on *Measure* (top left), then select *Slope* the software will show a sliding tangent line that you can move around with your mouse. The value of this tangent line slope will appear on the bottom right corner of your graph. This represents the slope at any point in time (instantaneous velocity) • If you click on *Analyze*, then select *Curve Fits*, you can select regions on the graph to fit to a straight line. The slope of this line is displayed in a table below the graph. The *value* of *Parameter A* will be the best fit slope of your region.

6. Use your graphs to determine the *mechanical energy* (kinetic and potential) at the three locations stated below. Show all calculations and label any heights and velocities determined directly onto the diagrams provided. **You may assume that the athlete has a mass of 75kg.**

Running down the track:	Halfway up:	At top:
		
Total mechanical energy, E_p+E_k *(show all data and calculations)* *Total mech energy =* _______ *J*	Total mechanical energy, E_p+E_k *(show all data and calculations)* *Total mech energy =* _______ *J*	Total mechanical energy, E_p+E_k *(show all data and calculations)* *Total mech energy =* _______ *J*

7. Examine your values for the mechanical energy at the three locations above. Has mechanical energy been *conserved* as the athlete soars through these positions? Explain why you think this is.

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Part 2: Mastery

1. There are many forms of potential energy. In this course we have only focused on gravitational potential energy, or $E_p = mgh$. You may think of potential energy as stored energy. In other words we could say that *mgh* represents the energy stored in an object due to its height (it wants to fall). List two other common forms of energy that could be considered as potential, or stored energy.
   a. ______________________________
   b. ______________________________
2. It is a law in physics that ***total** energy* (not just mechanical) must be conserved in a system. Compare the mechanical energy of the jumper while running down the track to that when the jumper is roughly half way to the top. Attempt to explain why the mechanical energy that you calculated has decreased at this point. Where has the energy gone? Has it been temporarily stored somewhere else? How do you know?

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3. Determine how much energy is temporarily stored in the pole while at the half way point.

   Energy stored in the pole at half way point (maximum flex of pole): Show all work.

   Energy in pole (at maximum flex) = ______________________ *J*

Efficiency of a system is defined as a percentage of the initial energy that is considered "useful" when all is said and done. For our pole-vaulter the goal is to ultimately convert as much of his original energy as possible into height (potential energy).

4. Why is it impossible for any system to be more than 100% efficient?

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5. Examine the vaulter's *mechanical energy* at the top compared to the *mechanical energy* as he runs down the track (the initial energy). In terms of efficiency do these numbers make sense? Why or why not?

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6. In order for *mechanical energy* to be conserved the system in question needs to be ***closed***. This means that no external forces can be present while the energy is being transformed. If additional work is done, the total energy of the system changes. While the pole itself is capable of temporarily storing energy, it must release this energy back when it returns to its original shape. The pole can NOT provide additional energy. Where did the additional energy that the pole-vaulter achieves at the peak come from?

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Part 3: Ace

1. Calculate the work done by the pole-vaulter *after* he plants the pole at rises to the peak. Show all steps below and annotate when necessary to help explain your logic.

Work done by the pole-vaulter while in the air. Show all steps below.
Work done by the vaulter, W = _______________ *J*

2. Step through the video slowly. Identify how this pole-vaulter is able to generate additional energy while rising to the apex. Discuss how he manipulates his center of mass.

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