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Kinetic Energy Investigation

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NGSS LESSON PLAN 1 (POETS) HS-PS3 INVESTIGATION

Grade: 11-12	**Topic: HS Kinetic Energy Investigation**	**Lesson # 1 (90 minutes) in a series of __ lessons.**

Brief Lesson Description:
Students will build a mouse trap powered car that converts elastic potential energy contained in the trap's spring to linear kinetic energy of the car. The release of this energy results in a net force which leads to linear acceleration. This acceleration can be measured with Vernier Logger Pro®, and using Newton's Second Law of Motion, the net force can be calculated. Finally, using the concept of work, the final kinetic energy of the car can be calculated.

Once students become familiar with the calculation of work and energy, the teacher will challenge the students to modify their cars to perform within a specific energy range. This may involve modifying mass, wheel design, lever action, etc.

The concept of work and energy is demonstrated in this lesson through the use of a student built car and Vernier Logger Pro®. The lesson utilizes concept application, data collection, and graphical modeling techniques to give the students an understanding of energy transfer by bridging concepts of kinematics and dynamics.

Before proceeding with this lesson, the teacher should familiarize him / herself with Vernier Logger Pro®:

***Vernier Logger Pro®* Overview:** https://www.vernier.com/products/software/lp/

Performance Expectation(s)/Standards:

HS-PS3-1 **Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.** [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [*Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.*]

HS-PS3-3. **Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*** [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [*Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.*]

Specific Learning Outcomes/Including Evidence Statements:

Observable features of the student performance for standard **HS-PS3-1**:		
1		Representation
	a	Students identify and describe* the components to be computationally modeled, including:
		i. The boundaries of the system and that the reference level for potential energy = 0 (the potential energy of the initial or final state does not have to be zero);
		ii. The initial energies of the system's components (e.g., energy in fields, thermal energy, kinetic energy, energy stored in springs — all expressed as a total amount of Joules in each component), including a quantification in an algebraic description to calculate the total initial energy of the system;
		iii. The energy flows in or out of the system, including a quantification in an algebraic description with flow into the system defined as positive; and
		iv. The final energies of the system components, including a quantification in an algebraic description to calculate the total final energy of the system.
2		Computational Modeling
	a	Students use the algebraic descriptions of the initial and final energy state of the system, along with the energy flows to create a computational model (e.g., simple computer program, spreadsheet, simulation software package application) that is based on the principle of the conservation of energy.
	b	Students use the computational model to calculate changes in the energy of one component of the system when changes in the energy of the other components and the energy flows are known.
3		Analysis
	a	Students use the computational model to predict the maximum possible change in the energy of one component of the system for a given set of energy flows.

	b	Students identify and describe* the limitations of the computational model, based on the assumptions that were made in creating the algebraic descriptions of energy changes and flows in the system.
Observable features of the student performance for standard **HS-PS3-3**:		
1	Using scientific knowledge to generate the design solution	
	a	Students design a device that converts one form of energy into another form of energy.
	b	Students develop a plan for the device in which they:
		i. Identify what scientific principles provide the basis for the energy conversion design;
		ii. Identify the forms of energy that will be converted from one form to another in the designed system;
		iii. Identify losses of energy by the design system to the surrounding environment;
		iv. Describe* the scientific rationale for choices of materials and structure of the device, including how student-generated evidence influenced the design; and
		v. Describe* that this device is an example of how the application of scientific knowledge and engineering design can increase benefits for modern civilization while decreasing costs and risk.
2	Describing criteria and constraints, including quantification when appropriate	
	a	Students describe* and quantify (when appropriate) prioritized criteria and constraints for the design of the device, along with the tradeoffs implicit in these design solutions. Examples of constraints to be considered are cost and efficiency of energy conversion.
3	Evaluating potential solutions	
	a	Students build and test the device according to the plan.
	b	Students systematically and quantitatively evaluate the performance of the device against the criteria and constraints.
4	Refining and/or optimizing the design solution	
	a	Students use the results of the tests to improve the device performance by increasing the efficiency of energy conversion, keeping in mind the criteria and constraints, and noting any modifications in tradeoffs.

Prior Student Knowledge:

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.** [Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object sliding down a ramp, or a moving object being pulled by a constant force.] [*Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.*]

Science and Engineering Practices

Developing and Using Models

Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

- Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS3-2),(HS-PS3-5)

Planning and Carrying Out Investigations

Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider

Disciplinary Core Ideas

PS3.A: Definitions of Energy

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (HS-PS3-1),(HS-PS3-2)
- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2) (HS-PS3-3)
- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which

Crosscutting Concepts

Cause and Effect

- Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. (HS-PS3-5)

Systems and System Models

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. (HS-PS3-4)
- Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. (HS-PS3-1)

Energy and Matter

- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-PS3-3) limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS3-4)

Using Mathematics and Computational Thinking

Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Create a computational model or simulation of a phenomenon, designed device, process, or system. (HS-PS3-1)

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-PS3-3)

mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-2)

PS3.B: Conservation of Energy and Energy Transfer

- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1)
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1),(HS-PS3-4)
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. (HS-PS3-1)
- The availability of energy limits what can occur in any system. (HS-PS3-1)
- Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (HS-PS3-4)

PS3.C: Relationship Between Energy and Forces

- When two objects interacting through a field change relative position, the energy stored in the field is changed. (HS-PS3-5)

PS3.D: Energy in Chemical Processes

- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3),(HS-PS3-4)

ETS1.A: Defining and Delimiting an Engineering Problem

Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. *(secondary to HS-PS3-3)*

- Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. (HS-PS3-2)

Connections to Engineering,Technology, and Applications of Science

Influence of Science, Engineering and Technology on Society and the Natural World

- Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HS-PS3-3)

Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Science assumes the universe is a vast single system in which basic laws are consistent. (HS-PS3-1)

Possible Preconceptions/Misconceptions:

Misconception: Some students may think an object at a constant velocity is accelerating.

- An object at a constant velocity has zero acceleration.
- Acceleration is defined as a change in velocity over a change in time.
- If there is no change in velocity, the object cannot be accelerating.
- Roll a model car equipped with an accelerometer at a constant velocity to demonstrate this concept.

LESSON PLAN – 5-E Model

ENGAGE: Opening Activity – Access Prior Learning / Stimulate Interest / Generate Questions:

Brainstorm with students about the concept of energy. Probe the class for a definition of energy. Ask for examples. Peak their interest by setting a rat trap on a table and placing a pencil in the trap. This will loudly and dramatically snap the pencil into pieces. Ask the students if this involved an energy exchange. If so, where did the energy come from?

Since energy was transferred from the spring of the trap to the pencil, could that energy be harnessed differently? Could it be used to do something useful, such as move a miniature car?

Homework project: Place the students in pairs. Their task is to build a mouse trap powered car that operates within the following parameters:

- **The car must roll freely on the ground and may not be attached to anything.**
- **The car may operate under mouse trap power only.**
- **The car must travel and continuously accelerate a minimum of 3 meters (approximately ten feet).**
- **The car must be robustly built to withstand several trials.**

While craft stores offer kits to build these, encourage students to do a simple YouTube search for design ideas.

One specific design link can be found at: https://youtu.be/mVNFxlEMWvw

Have student pairs brainstorm on designs, what materials they will need, and division of labor. They will need to be given a few days to complete the project outside of class.

This is also a great time to introduce students to the Vernier Logger Pro®. The easiest method of data collection, as well as the method outlined in this lesson plan, utilizes the video analysis feature of Logger Pro. A video link outlining the video analysis process is given below. A download link for Vernier Logger Lite® is also given. Please note that the analysis features of Logger Lite are limited compared to those of Logger Pro.

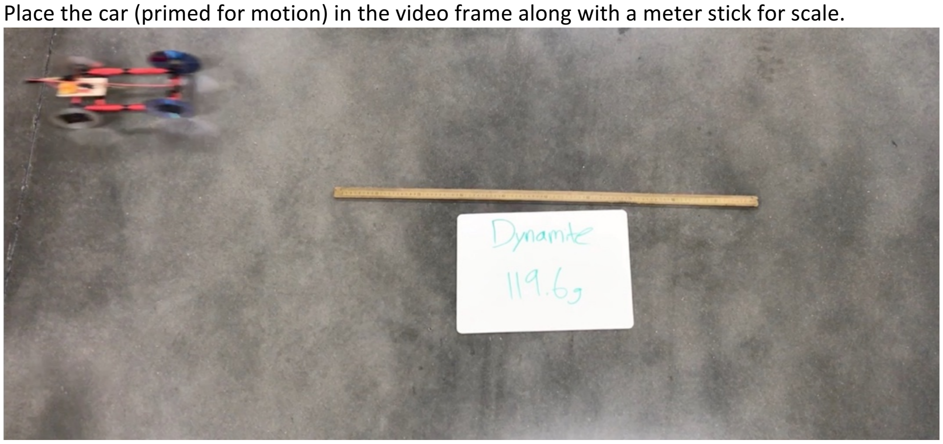
Video Analysis with Vernier Logger Pro: https://www.youtube.com/watch?v=shNPrswj_kA

Download Link for Vernier Logger Lite: https://www.vernier.com/products/software/logger-lite/

EXPLORE: Lesson Description – Materials Needed / Probing or Clarifying Questions:

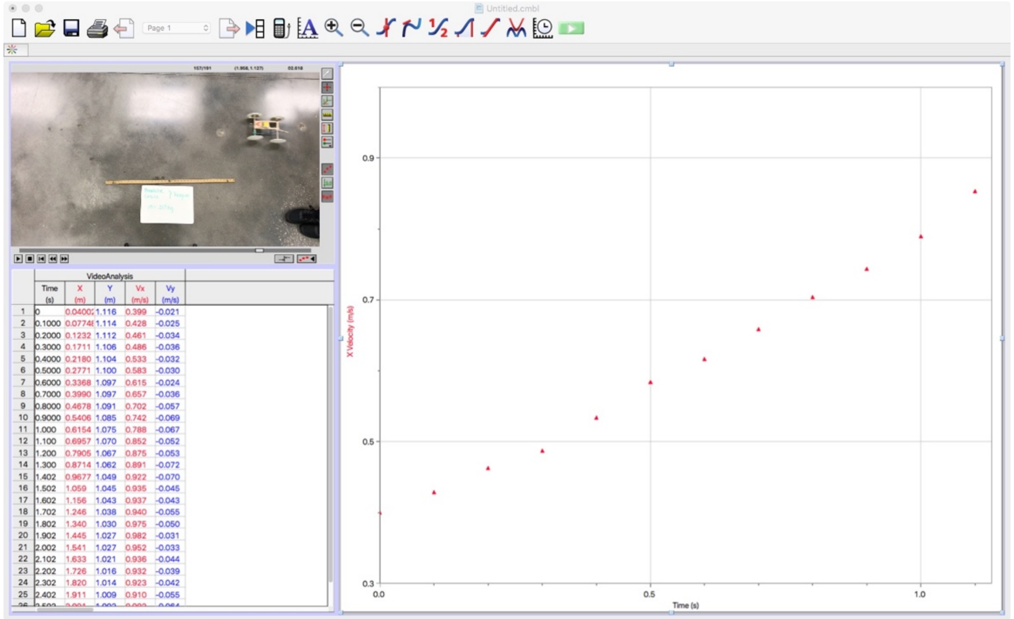
The data collection lesson can begin on the day the teacher makes the cars due. On that day, each student pair will work together at a computer station.

1. Today, students will make motion measurements on their cars using Vernier Logger Pro®.
2. Each student pair will need their mousetrap car, a smartphone or digital camera, and a computer with Vernier Logger Pro®.
3. Place the car on a balance to determine its mass.
4. Place the car (primed for motion) in the video frame along with a meter stick for scale.

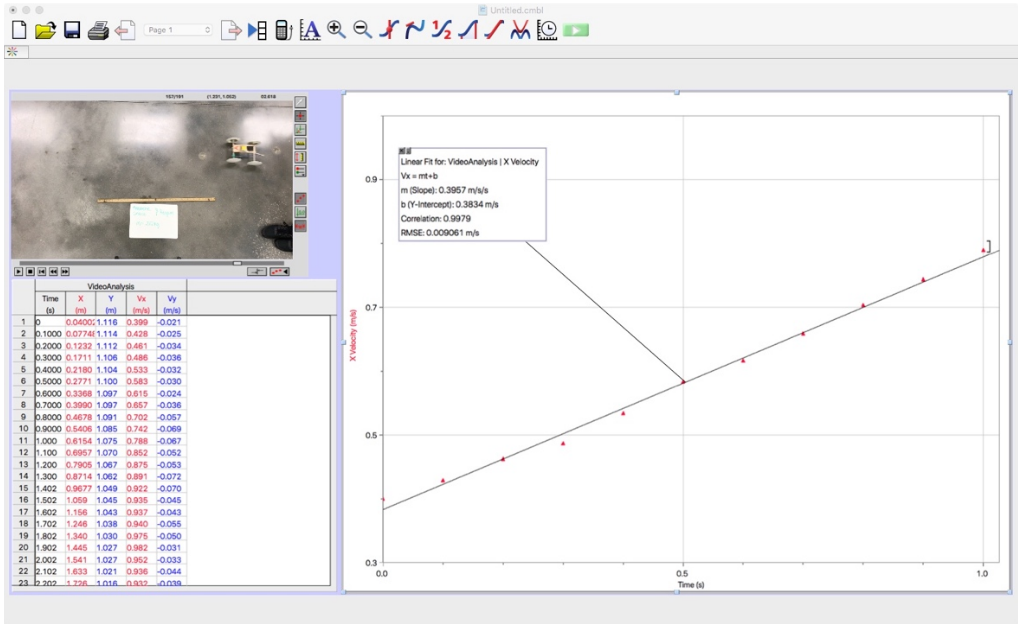


5. Begin recording. Be sure to set the camera as still as possible. Capture as much of the car's motion as possible.
6. Save the video to the computer with Vernier Logger Pro.
7. Import the video into Logger Pro.

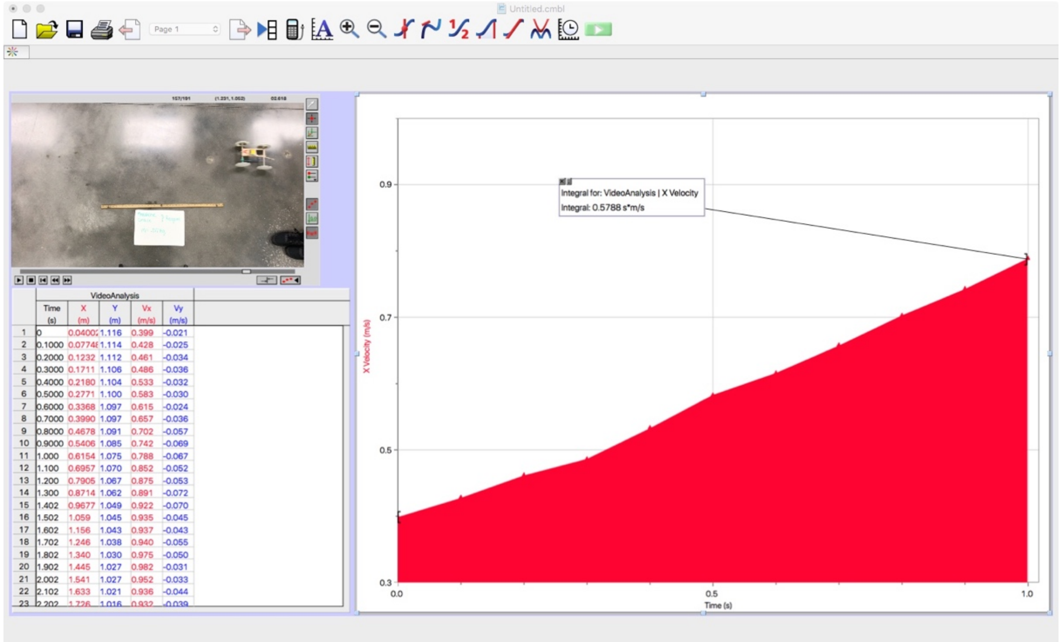
8. Analyze the car's motion to obtain a velocity-time graph.



9. The graph should be linear as a result of the car's uniform acceleration. Perform a linear fit on the graph to obtain the car's acceleration.



10. The area under the graph will tell us how far the car went in a particular time interval. Select data points within a particular time interval, and perform an integral fit to determine the displacement of the car.



11. asdf

<u>Materials:</u>

- 1 - Computer equipped with Vernier Logger Pro® per group
- 1 - Camera or smartphone (brought by student)
- 1 - Mouse trap powered car (student built) per group
- 1 - Meter stick for scale in video

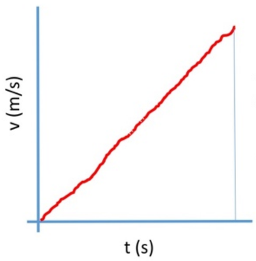
EXPLAIN: Concepts Explained and Vocabulary Defined:

For Students after the activity:

1. **What trends do you see in your data?**
2. **Share your data with other groups.**
3. **As a class, do you see the same trends?**

Since acceleration is constant for a specific amount of time, the final velocity can be determined by calculating v = at. Ask students what we can learn about the car's motion from the graph as a model of motion. ***Does the slope tell us anything?*** Since slope is defined as the rise of the line over the run of the line, the slope is the ratio of the change in velocity over change in time. *The slope is the acceleration that was measured with the acceleration v time graph*. ***Does the area under the line tell us anything?*** Since the line is angled, we have a triangular area under the graph. The area of a triangle is defined as ½ (base)(height), which translates to ½ (time)(velocity). Dimensionally, multiplying velocity be time gives displacement. *The area is the displacement of the car during the time interval.*

Using these relationships and the previously learned definition of **work being the product of force times displacement**, we can determine the amount of work the trap did to move the car:



Area under the graph:
$A = \frac{1}{2} b h$, which translates to

$\Delta x = \frac{1}{2} t \Delta v$

So if

$\Delta x = \frac{1}{2} t \Delta v$, $W = F \Delta x$, and $F = m a$

then

$W = m a \Delta x$, which gives us

$W = m a \frac{1}{2} t \Delta v$, which cleans up to

$W = \frac{1}{2} m \Delta v^2$

In order to do work, an object must have energy. This energy is displayed in the form of motion, so this is kinetic energy.

Now challenge students to brainstorm on modifications on their cars to increase kinetic energy output by 25% (or any amount of change directed by the teacher). Have the students modify the cars, return them, and test to determine if the energy output has changed.

<u>Vocabulary</u>:
Displacement: a change in position
Velocity: a change in position as a function of time
Acceleration: a change in velocity as a function of time
Mass: the quantity of matter in an object
Net Force: an unbalanced push or pull on an object that results in an acceleration
Work: force applied over a certain displacement
Energy: work done (or ability to do work) on or by an object

ELABORATE: Applications and Extensions:

The concept of work and energy demonstrated in this lesson can be further investigated by using a Texas Instruments® SensorTag. The SensorTag is a compact sensor array that connects wirelessly to mobile devices via Bluetooth.

Before proceeding with this extension, the teacher should familiarize him / herself with the Texas Instruments® SensorTag and their smartphone / tablet applications for basic functionality:

SensorTag Overview: https://www.youtube.com/watch?v=UhMKG761l78

iOS Application: https://itunes.apple.com/us/app/ti-sensortag/id552918064?mt=8

Android Application: https://play.google.com/store/apps/details?id=com.ti.ble.sensortag

The teacher should also familiarize him / herself with using the Texas Instruments® SensorTag with the N-spire Calculator and iPad application: *http://compasstech.com.au/SensorTag/index.html*

Energy calculations are extremely important in the automotive industry. Auto manufacturers are constantly looking for ways to make engines more powerful and efficient.

As a demonstration, enlist the assistance of a fellow teacher and his / her automobile. Attach a SensorTag into the engine compartment and close the hood. One the iPad application, select "IR Temperature" as a sensor to display data.

As the engine runs, students will notice that the engine is producing a large amount of heat. ***What is heat?*** Heat is energy that is causing air molecules to move. ***Where does this heat come from?*** The heat is simply wasted energy from the engine.

Challenge the students to determine ways of harnessing this wasted energy. This lesson can lead into a further investigation involving thermoelectric generators that can convert heat energy to electrical energy.

EVALUATE:
Formative Monitoring (Questioning / Discussion):
1. Why does the car move in the first place? What is causing it to move?
2. What trends do you see in your data of acceleration v time?
3. Can you translate the acceleration v time graph into a velocity v time graph with the given information?
4. Using the stated relationships, can you derive the kinetic energy equation?

Summative Assessment (Project Extension):

1. Did you determine plausible modifications to your car to increase its energy output?
2. Does your energy output conform to the stated guidelines?

Materials Required for This Lesson/Activity

Quantity	Description	Potential Supplier (item #)	Estimated Price
1 per group	Smartphone or camera for recording	Brought by student	
1 per district	Vernier Logger Pro	Vernier Science and Technology	$250 site license
1 per district	Vernier Logger Lite (limited, but free, alternative to Logger Pro)	Vernier Science and Technology	Free