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Mouse Trap Racer in the Computer Age!

Subject Area(s)	Algebra, data analysis and probability, measurement, physics, number and operations, science and technology
Associated Unit	None
Associated Lesson	None
Activity Title	Mouse Trap Racing in the Computer Age!
Header	Insert image 1 here, right justified to wrap

Image 1

ADA Description: A picture of a typical mouse trap racer.

Caption: A mouse trap racer.

Image file name: mouse_trap_racer1.jpg

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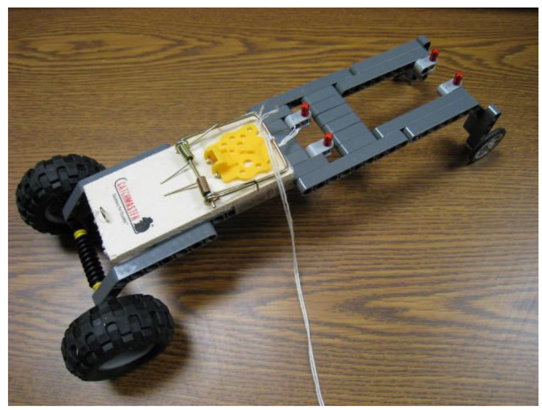

Grade Level	12(9-11)
Activity Dependency	None
Time Required	240 minutes
Group Size	3
Expendable Cost per Group	US$1

Summary

Students design, build, and evaluate a spring-powered mouse trap racer. For evaluation, teams equip their racers with an intelligent brick from a Lego Mindstorms Education kit and a Hitechnic acceleration sensor. Acceleration data collected during launch is used to compute velocity and displacement versus time graphs. In the process, students learn about the importance of fitting mathematical models to measurements of physical quantities, reinforce their knowledge of Newtonian mechanics, deal with design compromises, learn about data acquisition and logging, and carry out collaborative assessment of results from all participating teams.

Engineering Connection
A branch of engineering concerned with all aspects of automobile development is called automotive engineering. The goal of an automotive engineer is to design and build vehicles that realize desired specifications and cost constraints. Desirable specifications may include light weight, high engine power rating, large acceleration and top speed, high fuel efficiency, exceptional safety characteristics, and low cost – goals that may not all be achievable at the same time. Careful design tradeoffs must usually be made. After design, safety tests are often performed, for example those in which vehicle prototypes collide with a target in a controlled fashion. Acceleration sensors aboard the vehicle measure the magnitude of impact forces. A safe vehicle effectively dampens the force of impact, so as to result in low accelerometer readings – in a real accident, passengers are not subjected to excessive and dangerous forces.

Engineering Category
Category 1: relates science concept to engineering.
Category 2: relates math concept to engineering.
Category 3: provides engineering analysis or partial design.

Keywords
Acceleration, displacement, force, kinematic equations, model, programming, velocity

Educational Standards
- New York state
- New York state technology

Pre-Requisite Knowledge

Kinematic equations, Newton's second law, Hooke's law, basic rotational dynamics, sample mean and variance (optional), functions of time (i.e. acceleration, velocity, and displacement)

Learning Objectives
After this activity, students will be able to:
- Compute and plot velocity and displacement graphs from given acceleration data on the same time interval
- Explain the importance of fitting simple (linear) models to measurements
- Use intuition to predict performance of a mouse trap racer given the characteristics
- Explain sensor-based data acquisition/logging, and basic data analysis using a spreadsheet

Materials List
Each group needs:

- One Lego Mindstorms Education kit 9797
- One Hitechnic NXT Acceleration/Tilt sensor (NAC1040)
- One laptop or desktop computer with Lego Mindstorms NXT software v2.0, updated NXT firmware v1.26, imported Hitechnic accelerometer block, MS Office Excel 2007
- One mouse trap with trigger pin removed

To share with the entire class:

- Different diameter Lego wheels and miscellaneous Lego pieces
- String (nylon, kelvar, or equivalent)
- Roll of 1-2 inch packaging tape
- Meter stick
- Kitchen scale

Introduction/Motivation

The invention of the wheel and use of wheeled vehicles since 3500 BC brought about tremendous progress. Goods and people were transported much faster than was possible before, energizing commerce, strengthening military capabilities, increasing food supplies, and allowing many laborers to become artisans or even scholars. Wheeled vehicles were mostly driven by horses until the late 1700s, when steam engine vehicle prototypes were constructed, and 1880s, when first automobiles based on the internal combustion engine were built.

The basic principle behind a self-powered vehicle is to convert some form of potential energy into motion, or kinetic energy. There are many forms of potential energy, for example gravitational potential energy associated with an object at a certain distance from earth, elastic potential energy stored in a deformed spring, potential energy in a charged capacitor or current-carrying inductor, chemical potential energy in gasoline or battery, and others. The simplest vehicle can be built without any engine at all! How? (Illustrate by using gravitational potential energy – let a ball roll down an inclined surface.) Of course, a vehicle will be truly useful when it can move by itself on a level surface, or even up along a hill. This requires internal means of propulsion.

In this activity, each team will build and evaluate a mouse trap racer. The elastic potential energy in a set mouse trap will be the means of propulsion. A typical racer is shown in the image. It consists of a cart taped to a mouse trap. A piece of string is attached to the swinging trap bracket. In operation, this string is wound around the driving axle (in this case the rear axle), which also sets the trap. The driving wheels are held tightly until launch. Usually, it is best to remove the trigger pin and hold on to the driving wheels, since this makes for a well-controlled and repeatable launch. Let’s demonstrate with an example. (Demonstrate using a racer built ahead of time.)

What performance criteria can we use to evaluate a racer design? Let's first predict typical racer behavior. We can expect that, during launch, the racer will accelerate for as long as the string exerts a torque on the driving axle. Maximum velocity will be achieved just at the point when all of the string has unwound (the mouse trap has shut closed). The racer will then gradually come to a stop as friction forces act to oppose its forward motion. Therefore, one way to quantify the racer performance is by means of a table of values for the following quantities

- top acceleration
- top deceleration
- top velocity
- total distance travelled

Ideally, we would like the largest possible values for all these quantities, except top deceleration, which we would like to be as close to zero as possible. In other words, we would like to minimize friction forces. Since we will have access only to acceleration measurements, we will need to compute velocity and distance travelled from the measured acceleration versus time graph.

Let's now summarize some factors that affect mouse trap racer performance.

- *Mass* – by Newton's second law, for the same applied force, heavier masses will experience less acceleration. Make your design lightweight!
- *Driving wheel diameter and moment of inertia* – for the **same** rotation, wheels of larger diameter will cover a greater linear distance (illustrate using circumference arguments), and for the **same** diameter and applied torque, wheels with larger moment of inertia will undergo less linear acceleration (illustrate using the spinning buttons demo, as in the image below).
- *Driving wheel traction* – rubber tires provide better traction than plastic tires, and for the same tire material, larger surface contact results in better traction (perform the eraser demo, as in the image below). Use tires!
- *Time duration over which torque is applied to the driving wheels* – **same** torque applied for longer results in larger velocity and travelled distance.
- *Magnitude of the applied torque* – for the **same** moment of inertia and wheel diameter, larger applied torque results in larger linear acceleration.
- *Friction forces between the axles and racer body* – smaller friction forces result in less deceleration and therefore larger travelled distance. Make sure your axles rotate freely!

Is it possible to design a racer with the best possible values for all four parameters? Are there any compromises your team has to make (conduct a discussion)?

Insert image 2 here, centered

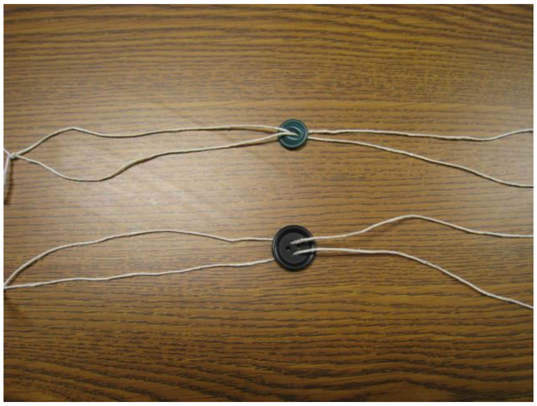

Image 2

ADA Description: An image showing two threaded buttons with different moments of inertia.

Caption: These threaded buttons have different moments of inertia. See video demonstration in references.

Image file name: mouse_trap_racer2.jpg

Source/Rights:

Insert image 3 here, centered

Image 3

ADA Description: An image showing that amount of friction increases with increasing contact area.

Caption: An eraser is easier to push when lying on its narrow side.

Image file name: mouse_trap_racer3.jpg

Source/Rights:

Image 4

ADA Description: An image showing that amount of friction increases with increasing contact area.

Caption: It is harder to push an eraser lying on its broad side.

Image file name: mouse_trap_racer4.jpg

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Vocabulary/Definitions

Word	Definition
Acceleration	Change in velocity at two time instants, divided by the time interval.
Displacement	Distance travelled between two time instants.
Velocity	Displacement between two time instants, divided by the time interval.
Potential energy	Energy in a system that can be used to perform work.
Kinetic energy	Energy associated with a system with nonzero velocity.
Torque	A measure for the tendency of an object to rotate about an axis when subjected to a force.
Accelerometer	A sensor used to measure acceleration.
Data acquisition	Usually, a process in which measurements are made under computer control.
Data logging	A process of storing measurements in a computer file.
Algorithm	A sequence of logical steps that achieve a given objective, and are intended to be programmed into a computer.

Procedure

Before the Activity

- Prepare demonstration materials (ball, inclined beam, mouse trap racer, threaded buttons, eraser).

- Prepare activity materials. Have a copy of the data analysis spreadsheet and the NXT Mindstorms program on each computer.
- Make copies of relevant worksheets.

With the Students

1. Divide the class into groups of three.
2. Introduce the activity and provide motivation. Supplement with relevant formulas from worksheets as needed.
3. In groups, have students brainstorm and then build their mouse trap racer. Groups should develop as many different designs as possible, in order to make collaborative assessment a success – encourage creativity! Provide the following general guidelines.
    - Tape should be used sparingly to hold the mouse trap in place. Show that tape is only needed on the bait side of the mouse trap (why?). Also, show an example of how worm gears can be effectively used on the driving axle (see video in references).
    - The NXT brick should be placed away from the metal trap bracket.
    - **Important:** the acceleration sensor should be mounted as parallel to the ground as possible, and with the x-axis pointing in the direction of motion. Tilting the accelerometer with respect to the ground will results in erroneous measurements.

Insert image 5 here, centered

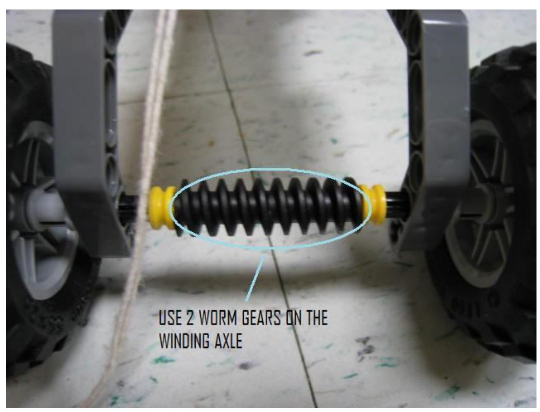

Image 5

ADA Description: An image showing how worm gears can be mounted on the driving axle.

Caption: Worm gears can hold a wrapped string tightly in place.

Image file name: mouse_trap_racer5.jpg

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Insert image 6 here, centered

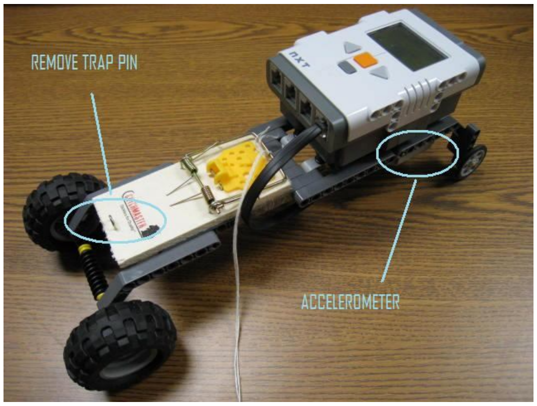

Image 6

ADA Description: An image showing one way to mount the NXT Lego brick on the racer.

Caption: One way to mount the NXT brick.

Image file name: mouse_trap_racer6.jpg

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Insert image 7 here, centered

Image 7

ADA Description: An image showing the x-axis of the acceleration sensor.

Caption: Mount your accelerometer with the x-axis pointing in the direction of motion, parallel with the floor.

Image file name: mouse_trap_racer7.jpg

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4. Have students open the NXT program **mousetrap.rbt**, which is shown in Image 8. Explain the algorithm. The program essentially waits for appreciable accelerometer readings, then starts logging time and acceleration readings in files **time.txt** and **acceleration.txt** located on the NXT brick. Each repetition of the experiment appends (does not delete) data collected from previous trials. 100 data values are collected for each trial. Data from each trial is separated by a space. Have students consult help menus, and provide extra assistance.

Insert image 8 here, centered

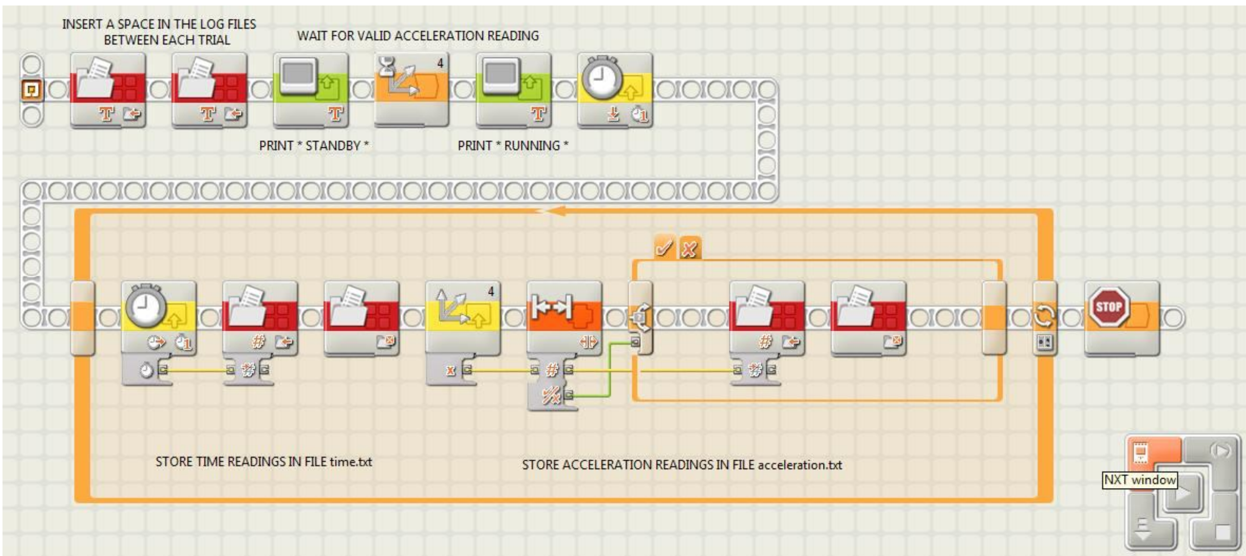

Image 8

ADA Description: An image showing the NXT Mindstorms program used to program the mouse trap racer.

Caption: This program is used to collect acceleration measurements with corresponding time values.

Image file name: mouse_trap_racer8.jpg

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5. Connect the NXT brick to the computer using the programming cable in the NXT Mindstorms Education kit. Go the the **NXT window** by pressing the orange button in the lower right hand corner in Image 8. In the window, under the **Communcations** tab, verify that the NXT is connected. Click on the **Memory** tab. Notice how much memory is taken up by programs and data (if any). Click **Delete All**. Notice how more memory is now available. The panel labeled **NXT Data** lists some useful information, such as your battery status (recharge the battery if needed). Now click **Close**.
6. Download the program **mousetrap.rbt** to the NXT brick by clicking on the **Download** button in the lower right hand corner in Image 8 (hold your mouse pointer over each button to read its function). Now go to the **NXT window** again, and verify that your program has downloaded successfully. Now click **Close**, and disconnect the programming cable. You are now ready to run the mouse trap racer and log data!
7. Wind the string around the driving axle, thereby setting the mouse trap. Set the racer up against a wall, holding on to the wheels. Find the program **mousetrap** on your brick, and be

ready to run it the moment after launch. When ready, launch your racer (see sample launch video in references). Allow both racer **and** program to fully stop before proceeding.

8. Go to the **NXT window** and under **Memory** tab, verify that log files **time.txt** and **acceleration.txt** have been created (these should be under the heading **Other**). Select the file **time.txt** and click **Upload**. Choose the Desktop folder and click **OK**. The log file with time values should now be located on your desktop. Repeat the procedure to upload the file **acceleration.txt**. Notice that if these files are already on your desktop, overwrite them with those you have generated.
9. Open the spreadsheet **Analysis_Spreadsheet.xls**. Go to the sheet labeled *Raw Data* (click on the tab in the lower left hand corner of the screen). Notice how sample data has been filled in the **time (ms)** and **Trial 1** columns. Go to the Desktop, and open the file **time.txt** in Notepad. Highlight and copy the time data. In Excel, select (click on) cell A3, and paste your time values. Now scroll down to make sure you have not entered any values beyond the cell A102. Repeat the procedure with the data in file **acceleration.txt**.
10. Now go to the sheet *Analysis*. You will need to type in values in the cells highlighted in red. Cell H3 is the time value at which your racer achieves its highest velocity. Eyeball the acceleration data and roughly note the point at which acceleration values max out. Type in the corresponding time value in cell H3. Cell H4 is the time value at which your racer comes to a stop. Eyeball the acceleration data, and roughly note the point at which acceleration values become very small and mostly constant (ideally zero). Enter the corresponding time value in cell H4.
11. Now look at the plots in the sheet *Graphs*. Notice how noisy the measured acceleration values are (look at the graphs in the first column). Does your velocity graph reflect reality? What about the displacement graph? Look at the second column, where we fit a model using two constants in the time intervals 0 to t_1 and t_1 to t_2. Try to answer the same questions. Repeat with the third column, where we use a model of two line segments over the same time intervals to model the racer acceleration profile.
12. Now gather data for nine more trials. That is, repeat the launch procedure to obtain acceleration data for ten trials. You don't need to upload the data to Excel every time, since the log files will be appended (not overwritten) with new data each time you run the program **mousetrap**. After you are done, upload your log files to Desktop as before (see sample attached log files). Copy and paste acceleration data from file **acceleration.txt** in columns C3 through K3. Time values do not change, so time data needs to be entered only once. Type in new values for t_1 and t_2 in the cells highlighted in red, but use the **average of raw readings** (column B in the *Analysis* sheet) to estimate these times.
13. **Analysis**: The sheet *Analysis* does several things.
    - Column D contains acceleration readings in the proper units (m/sec^2). In column E and F, we compute velocity and displacement. Refer to the Analysis Worksheet for formulas.
    - In columns H through O, we fit a model that assumes constant acceleration over the two time intervals 0 to t_1 and t_1 to t_2 (**Model 1** – piecewise constant model). We use a procedure called constrained least squares, details of which are optional, but are given in the attachment Derivations.
    - In columns Q through EH, we use constrained least squares to fit two lines over the time intervals 0 to t_1 and t_1 to t_2 (**Model 2** – piecewise linear model).

14. Go to the sheet labeled *To Submit*, and type data into cells highlighted in red. Weigh your racer, and enter the mass in grams. Measure the driving wheel diameter, and length of string wrapping around the driving axle, and enter those values. Submit this table to your teacher.

Attachments

Statistics_Worksheet.doc

Analysis_Worksheet.doc

Analysis_Spreadsheet.xls

Derivations.pdf

sample_time.txt

sample_acceleration.txt

Safety Issues

- Ask students to exercise caution when setting the mouse trap. Keep fingers away from the bait area and sharp or rough edges.

Troubleshooting Tips

- Students may encounter the problem in which, instead of numbers, their log files contain the character **ÿ**. If this happens, have students manually delete such characters using Notepad. Correctly formatted log files should look like the files **sample_time.txt** and **sample_acceleration.txt** in the attachments.
- Sometimes, the NXT may omit a carriage return after one or more entries. Have students manually correct this problem in Notepad before copying data into Excel.
- In case of corrupted or incorrectly gathered data, have students delete their log files from the **NXT memory** window, and rerun the experiment.

Investigating Questions

Collect the *To Submit* data from all teams, and make plots of performance metrics versus racer weight, wheel diameter, and string length. Conduct a collaborative class discussion.

- How is top acceleration related to the mass and wheel diameter of the mouse trap racer?
- How is top velocity related to the racer mass and wheel diameter?
- How is total displacement related to the wheel diameter and string length?
- Which model fit most resembles the average acceleration versus time graph?

Discuss individual team results.

- Do plots in the first column in sheet *Plots* reflect reality? For example, does your computed velocity ever become negative? Does your total displacement ever decrease? If yes, why do you think this is so?
- Do plots in the second column (**Model 1**) in sheet *Plots* reflect reality? For example, can we really assume constant acceleration over time interval 0 to t_1, given that the torque applied to the axle by the mouse trap bracket is proportional to the bracket angle

(Hooke's law)? Nevertheless, is this a reasonable approximation? Compare the maximum displacement value with the actual measured distance your racer travels.

- Repeat for plots in the third column (**Model 2**). How does this model compare to **Model 1**? Is **Model 2** more accurate? If yes, why do you think so? Explain using physics arguments.

Assessment

Pre-Activity Assessment

Sharing Experiences: Lead a class discussion about student experiences with cars. Who likes sporty sedans? What about fuel efficient/hybrid vehicles? Bikes?

Activity Embedded Assessment

Analysis and Statistics Worksheets.

Post-Activity Assessment

Collaborative assessment of group results.

Activity Scaling

- For lower grades, adapt Statistics and Analysis Worksheets as needed.
- Have calculus physics students compute velocity and displacement from acceleration data using trapezoid and other integration rules.

Additional Multimedia Support

Spinning a button with small moment of inertia, Accessed February 16, 2010.
http://www.youtube.com/watch?v=s_MmgT7anB0
Spinning a button with high moment of inertia, Accessed February 16, 2010.
http://www.youtube.com/watch?v=JFKsy-oLdcc
Preparing the mouse trap racer for launch, Accessed February 16, 2010.
http://www.youtube.com/watch?v=RzD8Q3kV2wc
A typical launch, Accessed February 16, 2010.
http://www.youtube.com/watch?v=cVZygfxm848

References

Glencoe Physics: Principles & Problems, Paul W. Zitzewitz, 2002, Glencoe/McGraw-Hill
Conceptual Physics, 9th edition, Paul G. Hewitt, 2002, Addison Wesley

Redirect URL http://gk12.poly.edu/amps-cbri

Owner Pavel Khazron

Contributors Pavel Khazron

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