RICH CULMINATING ACTIVITY USING AN ELECTRIC CAR MODEL (SPH3U, SPH4C)

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Inquiry-based Multi-Strand Culminating Activity Using a Model Electric Car

Strands and Units: Kinematics, Forces, Energy and Society, Electricity and Magnetism

Grade Eleven University Physics (SPH3U)

Overview: Students will be introduced, through an engaging video, to the concepts of speed and acceleration for linear motion, as well as being introduced to battery-powered transportation. As they are watching the video they will be expected to record any information they think is relevant to calculating kinematic parameters. They will be placed into groups of two to four students and asked to do basic research for performance data taken from either of these resources, http://www.nedra.com/records-sp.html (http://www.nedra.com/records-sp.html) or https://www.youtube.com/watch?v=zp8_0EwNaV4 (https://www.youtube.com/watch?v=zp8_0EwNaV4). These data will then be used to introduce some of the basic uniform motion and acceleration concepts used in this course. Formative instruction can include the exemplars found in the copy of the student journal. The teacher can use these exemplars as examples of the calculations.

The students will then build a pre-designed model of a very basic electric car, and perform basic time-distance measurements on its movement. This will give them data that they will use to graph distance-time data for its motion, determine the car's acceleration, determine its final velocity and, later in the semester, calculate its energy consumption and loss.

Inquiry Focus: Students will build and study a basic model electric vehicle that they will analyse graphically and mathematically, determining kinematic, dynamic, energy and electrical parameters. They will then use this information to calculate kinetic energy, power and electrical energy used. Energy transformation will also be studied using batteries and a multimeter. From this data they will calculate efficiency and determine an approximate value for the force of friction in the entire drive system.

Timeline: This culminating activity begins within the first three days of the course, and continues periodically as each of the aforementioned units draw to a close. The data are revisited and layers of understanding are added as the course progresses toward the culminating period. Specific timelines depend on the course and school culminating schedule, but a total of about six class days is used throughout the semester. This includes three days as a culminating activity.

Important Note: This is a culminating activity and does not include any specific material related to summative evaluation at the end of each unit. It is assumed in creating this project that the teacher will incorporate whatever summative material is necessary to evaluate each unit throughout the course. That is what the author did. The teacher may also wish to start this project between the kinematics and dynamics units.

Accommodations: This activity requires a broad range of skills and with groups of three or four, tasks can be separated so that the activity is differentiated in ways that the students can decide. For example, I had one student who, due to a genetic disease, had difficulty manually assembling the car. He was able to comfortably do data recording on a handheld device and make that available to his partners. He also had difficulty drawing tangents accurately but was able to use a spreadsheet program to draw the graph, enabling him to estimate tangents more accurately on a printout.

Ultimately each student should, of course, be able to perform the calculations independently using the collected or, in some cases, provided data.

Day 1 – First day of course, introduction to terminology, Watch videos, TPS on data, begin car construction

Day 2 – Car construction continues, data collection may begin for some groups

Day 3 – Data collection, graphing, lesson on tangent vs. secant, instantaneous vs. average speed

Day 4 – Half period, wrap-up, summary of results for whole class

Day 5, Day 1 of culminating – During culminating period near end of course, verify that data and graph is in good order, fix any issues, measure current and voltage of car under load, calculate power and energy used.

Day 6, Day 2 of culminating – Hand out culminating worksheet, complete over 1-1/2 periods.

Big Ideas:

Kinematics

- Motion involves a change in the position of an object over time.
- Motion can be described using mathematical relationships.
- Many technologies that apply concepts related to kinematics have societal and environmental implications.

Forces

- Forces can change the motion of an object.
- Applications of Newton’s laws of motion have led to technological developments that affect society and the environment.

Energy and Society

- Energy can be transformed from one type to another.
- Energy transformation systems often involve thermal energy losses and are never 100% efficient.

Electricity and Magnetism

- Relationships between electricity and magnetism are predictable.
- Electricity and magnetism have many technological applications.
- Technological applications that involve electromagnetism and energy transformations can affect society and the environment in positive and negative ways.

Overall Expectations:

- **A1.** demonstrate scientific investigation skills (related to both inquiry and research) in the four areas of skills (initiating and planning, performing and recording, analysing and interpreting, and communicating);
- **B1.** analyse technologies that apply concepts related to kinematics, and assess the technologies’ social and environmental impact;
- **B2.** investigate, in qualitative and quantitative terms, uniform and non-uniform linear motion, and solve related problems;
- **B3.** demonstrate an understanding of uniform and non-uniform linear motion, in one dimension.
- **C1.** analyse and propose improvements to technologies that apply concepts related to dynamics and Newton’s laws, and assess the technologies’ social and environmental impact;
- **C2.** investigate, in qualitative and quantitative terms, net force, acceleration, and mass, and solve related problems;
- **C3.** demonstrate an understanding of the relationship between changes in velocity and unbalanced forces in one dimension.
- **D1.** analyse technologies that apply principles of and concepts related to energy transformations, and assess the technologies’ social and environmental impact;
- **D2.** investigate energy transformations and the law of conservation of energy, and solve related problems;

- **D3.** demonstrate an understanding of work, efficiency, power, gravitational potential energy, kinetic energy, nuclear energy, and thermal energy and its transfer (heat).

Specific Expectations:

A1.1 formulate relevant scientific questions about observed relationships, ideas, problems, or issues, make informed predictions, and/or formulate educated hypotheses to focus inquiries or research

A1.2 select appropriate instruments (e.g., probeware, calorimeters, pendulums, solenoids) and materials (e.g., drag sleds, electric bells, balls, ramps), and identify appropriate methods, techniques, and procedures, for each inquiry

A1.4 apply knowledge and understanding of safe laboratory practices and procedures when planning investigations by using appropriate personal protection

A1.5 conduct inquiries, controlling relevant variables, adapting or extending procedures as required, and using appropriate materials and equipment safely, accurately, and effectively, to collect observations and data

A1.6 compile accurate data from laboratory and other sources, and organize and record the data, using appropriate formats, including tables, flow charts, graphs, and/or diagrams

A1.7 select, organize, and record relevant information on research topics from a variety of appropriate sources, including electronic, print, and/or human sources, using suitable formats and an accepted form of academic documentation

A1.8 synthesize, analyse, interpret, and evaluate qualitative and/or quantitative data; solve problems involving quantitative data; determine whether the evidence supports or refutes the initial prediction or hypothesis and whether it is consistent with scientific theory; identify sources of bias and/or error; and suggest improvements to the inquiry to reduce the likelihood of error

A1.9 analyse the information gathered from research sources for logic, accuracy, reliability, adequacy, and bias

B1.1 analyse, on the basis of research, a technology that applies concepts related to kinematics [IP, PR, AI, C]

B1.2 assess the impact on society and the environment of a technology that applies concepts related to kinematics [AI, C]

B2.1 use appropriate terminology related to kinematics, including, but not limited to*: time, distance, position, displacement, speed, velocity,* and *acceleration* [C]

B2.2 analyse and interpret position–time, velocity–time, and acceleration–time graphs of motion in one dimension (e.g., use tangent slopes to create velocity–time graphs from position–time graphs and acceleration–time graphs from velocity–time graphs)

B2.3 use a velocity–time graph for constant acceleration to use the equation for average velocity

[e.g., $v_{av} = (v1 + v2)/2$] and the equations for displacement [e.g., $\Delta d = ((v1 + v2)/2)\ \Delta t$, $\Delta d = v1\Delta t + ½\ a\ (\Delta t^2)$], to solve simple problems in one dimension. [AI]

B2.4 conduct an inquiry into the uniform and non-uniform linear motion of an object [PR]

B2.6 plan and conduct an inquiry into the motion of objects in one dimension, using vector diagrams

and uniform acceleration equations [IP, PR, C]

B2.7 solve problems involving uniform and non-uniform linear motion in one and two dimensions, using graphical analysis and algebraic equations [AI, C]. Understanding Basic Concepts

B3.1 distinguish between the terms *constant*, *instantaneous*, and *average* with reference to speed, velocity, and acceleration, and provide examples to illustrate each term

C1.1 analyse, with reference to Newton's laws, a technology that applies these laws (e.g., extremely low friction bearings, near frictionless carbon, different types of athletic shoes, roller coasters), and propose ways to improve its performance [AI, C]

C1.2 evaluate the impact on society and the environment of technologies that use the principles of force [AI, C]

C2.1 use appropriate terminology related to forces, including, but not limited to: *mass, time, speed, velocity, acceleration, friction, gravity, normal force,* and *free-body diagrams* [C]

C2.2 conduct an inquiry that applies Newton's laws to analyse, in qualitative and quantitative terms, the forces acting on an object, and use free-body diagrams to determine the net force and the acceleration of the object [PR, AI, C]

C2.3 conduct an inquiry into the relationship between the acceleration of an object and its net force and mass and analyse the resulting data [PR, AI]

C2.4 analyse the relationships between acceleration and applied forces such as the force of gravity, normal force, force of friction, and solve related problems involving forces in one dimension, using algebraic equations [AI, C]

C2.5 plan and conduct an inquiry to analyse the effect of forces acting on objects in one dimension,

Using Newton's laws [IP, PR, AI, C]

C3.1 distinguish between, and provide examples of, different forces (e.g., friction, gravity, normal force), and describe the effect of each type of force on the velocity of an object

C3.3 state Newton's laws, and apply them, in qualitative terms, to explain the effect of forces acting on objects

D2.1 use appropriate terminology related to energy transformations, including, but not limited to:

mechanical energy, gravitational potential energy, kinetic energy, work, power, fission, fusion, heat, heat

capacity, temperature, and *latent heat* [C]

D2.2 solve problems relating to work, force, and displacement along the line of force [AI]

D2.3 use the law of conservation of energy to solve problems in simple situations involving work, gravitational potential energy, kinetic energy, and thermal energy and its transfer (heat) [AI]

D2.5 solve problems involving the relationship between power, energy, and time [AI]

D2.6 conduct inquiries and solve problems involving the relationship between power and work

D3.1 describe a variety of energy transfers and transformations, and explain them using the law of conservation of energy

D3.2 explain the concepts of and interrelationships between energy, work, and power, and identify

and describe their related units

D3.3 explain the following concepts, giving examples of each, and identify their related units: *thermal energy, kinetic energy, gravitational potential energy, heat, specific heat capacity, specific latent heat, power,* and *efficiency*

D3.5 describe, with reference to force and displacement along the line of force, the conditions that are required for work to be done

F1.1 analyse the social and economic impact of technologies related to electromagnetism [AI, C]

F2.1 use appropriate terminology related to electricity and magnetism, including, but not limited to: *direct current, alternating current, conventional current, electron flow, electrical potential difference, electrical resistance, power, energy, step-up transformer,* and *step-down transformer* [C]

F2.8 construct a prototype of a device that uses the principles of electromagnetism and test and refine their device [PR, AI]

F3.1 describe the properties of magnetic fields in permanent magnets and electromagnets (e.g., the three-dimensional nature of fields, continuous field lines, fields around current carrying conductors and coils)

F3.2 explain, by applying the right-hand rule, the direction of the magnetic field produced when electric current flows through a long straight conductor and through a solenoid

Key Concepts:

- Linear motion can be described using a displacement-time graph
- Uniform motion can be measured using a d-t graph, and calculations can be performed using a simple equation
- Uniform acceleration can be shown on a d-t graph, tangents measured to determine velocity-time and the acceleration measured using the v-t graph
- The uniform acceleration equations can be used to perform calculations on numbers obtained from uniform acceleration graphs
- Work, kinetic energy, mechanical power and net force can be calculated using mass and information from a d-t graph
- Electrical power consumed can be measured while an electric vehicle is accelerating
- Energy consumed and applied force can be calculated from electrical power data on an electric vehicle
- Frictional force can be calculated from net force and applied force
- The potential impact on society of electric vehicles can be assessed by performing literature searches
- The law of conservation of energy is demonstrated in the project

Prior Skill Sets and Knowledge:

- Good data collection and graphing skills
- Perform unit conversions within and between metric and SAE
- Ability to re-arrange equations using basic algebra
- Ability to perform simple measurements with rulers
- Ability to use simple hand tools, including cutters and hot glue guns
- How to measure current and voltage using a digital multimeter
- How to construct a simple series circuit (for the motor circuit)
- Graphing d – t graph, independent vs. dependent variable
- Interpolating tangents from graphs, measuring slope using a rate triangle (They may need a lesson on tangents and their meaning. There are plenty of good print and online resources for this.)
- Entering data in to a formula and calculating results
- Using a meter for measuring current and voltage

Instructional Planning and Delivery:

Day 1 – First day of course, introduction to electric cars and terminology. Students will watch one or more videos related to electric car racing (https://www.youtube.com/watch?v=zp8_0EwNaV4 (https://www.youtube.com/watch?v=zp8_0EwNaV4)) and summarize any physics terminology they notice, and record them in their journals. After the viewings a ten minute Think-Pair-Share (TPS) session will follow, during which groups will summarize their information in a way that is presentable to the class. Each group will then quickly present ONE piece of information to the class, and a recorder will summarize the information as it is presented. Chart paper or a Smart Board can be used for this.

Once this summary is completed a copy of the formula sheet (formula sheet link) can be handed out, and students will look at the uniform motion, uniform acceleration, energy and electricity and magnetism sections. They will circle or otherwise summarize the formulas that they can use with given or easily gotten information. Again, a TPS session will ensue as a class summary is produced, and the results will be recorded in their journals. This may start to bleed in to Day 2. As a TPS the formulas will be used with the available data, and summarized as a class. A summary of formulas that could be used is found in the appendix (insert link here). Students should be able to glean m, v_i, (usually = 0), v_f, P (mechanical and possibly electrical), Δt and Δd. They should be able to easily calculate a and E_k.

Summary of physics terms: speed, velocity, acceleration, time, distance, horsepower, current, voltage

Students will then be introduced to the electric car construction using this video (video of car construction here). Groups of two or three will be formed and materials handed out in a way that the teacher deems appropriate. It is suggested that kits be made ahead of time if time permits. A parts list for each kit can be found in the appendix.

Day 2 – Construction of the car will continue. If groups have completed their vehicle they may begin the process of collecting the necessary kinematics data. Once the data have been collected they may begin making a time-distance graph. From this they will generate five tangents during acceleration, and graphically verify the time when the car is moving constant speed. This can be done simply by laying a ruler on top of the line of best fit and demonstrating that there is a constant slope over this Δt range. This will likely bleed in to day 3 for many groups.

Day 3 – A lesson on tangents vs. secants and instantaneous speed vs. average speed will be given. Graphing will continue, and calculation of five instantaneous speeds, including the zone of constant sped, will be derived from the graph. Some self-guided learning resources are given here:

https://www.youtube.com/watch?v=bSxxgAO_2LA (https://www.youtube.com/watch?v=bSxxgAO_2LA)

https://www.youtube.com/watch?v=b3l2TsgpxeM (https://www.youtube.com/watch?v=b3l2TsgpxeM)

https://www.youtube.com/watch?v=hRhAqd84-Ic (https://www.youtube.com/watch?v=hRhAqd84-Ic)

Day 4 – Graphing will continue, and in their journal students will record their acceleration value that they got from the graph and by using the appropriate kinematics equation. They will also record their final speed, distance and time for acceleration. They will also record any other values they will be able to calculate from the kinematics equations in the appendix. They may wish to measure the mass of their vehicle to calculate kinetic energy at the final velocity.

To wrap up this investigation groups will come up and summarize their findings. If any group was unable to get good data with their vehicle they have the option of using another group's raw data, or, if necessary, another group's car. I would encourage teachers to ensure that EVERY group has processed data in as raw a form as possible.

Day 5 – This will be later in the semester, either during a prescribed culminating period or after the E&M unit is completed. Students will retrieve their journals (which will have been used for other things during the semester, no doubt) and revisit their data from the beginning of the courses. They will work in their groups to ensure that they have the data they need to complete the given culminating activity, that their graphs are in good order and to take the final power data from their car using a pair of multimeters. Once they have all the data they need they will return to their desks and begin the solo part of the culminating evaluation.

Days 6 – Completion of the solo part of the culminating evaluation.

Student Support Resources: Students will use their journals and will perform calculations based on class discussions.

Related Background Resources and/or Links: Classroom textbook.

Assessment Opportunities:

For Learning

The teacher will circulate and ensure that every student has quality good graphs and has performed calculations accurately. It's very important that the teacher check on every student to verify these. Please refer to the journal exemplar to use as a guide for how calculations should be done. They should include the following:

- The slopes of the five tangents interpolated from the graph
- The acceleration based on the final speed, as measured from the graph
- The kinetic energy that the vehicle has obtained, calculated from its mass and final speed.
- The acceleration that the vehicle underwent from $t = 0$ until final speed was achieved
- The power consumed by the car
- The amount of work done on the vehicle by the motor, using $W = \Delta E$ $\Delta E = P\ \Delta t$

As Learning

A check-in with each student to assess level of engagement, a short calculating of the above values could be given.

Of Learning

A summative test could be given after the work is done, but it's more likely that each expectation will be evaluated through the course as each unit is taught. The teacher may also decide to have the students hand in the kinematics and graphing part of this earlier in the semester and use it as a summative evaluation. I didn't do that.

Future Opportunities / Extensions: Short projects could be developed that involve the following STEM topics:

- Are electric vehicles a viable alternative form of transportation
- Are electric vehicles truly GHG free?
- What are the environmental impacts of electric vehicle production and use?
- What are the economics of electric vehicle production and use?

Appendix

1. **List of videos**

https://www.nationalgeographic.org/video/edu-electric-vehicles/ (https://www.nationalgeographic.org/video/edu-electric-vehicles/)

https://globalnews.ca/video/4157074/montreal-electric-vehicle-show (https://globalnews.ca/video/4157074/montreal-electric-vehicle-show)

https://globalnews.ca/video/4339586/montreal-lawyer-finds-dream-job-making-electric-skateboards/ (https://globalnews.ca/video/4339586/montreal-lawyer-finds-dream-job-making-electric-skateboards/)

https://www.youtube.com/watch?v=rikdqAGcyC8 (https://www.youtube.com/watch?v=rikdqAGcyC8)

https://www.youtube.com/watch?v=zp8_0EwNaV4 (https://www.youtube.com/watch?v=zp8_0EwNaV4)

2. **Expected formulas and data: use the formula sheet link in the sidebar.**
3. **Car parts list and sources**

1	3v to 6V toy motor
3	50mm wheels, 4mm axle hole
1	AA battery holder with switch
1	12mm gear with hole for motor shaft
1	30mm gear with 4mm hole for axle
1	axle 4mm X 30mm (rear)
1	axle 4mm X 80mm (front)
1	piece of straw, just over 4mm diameter, 140mm long
3	strut pieces, 4mm X 30mm

All of these parts can be purchased for reasonable cost at Kidder Scientific in Toronto www.kidder.ca (http://www.kidder.ca)

1. Ticker tape timer or electronic range finder with interface and software for collecting d – t data (see data collection video)

4. **List of Resources**

Print

1. Culminating handout (student copy)
2. Culminating handout (teacher copy)

3. Exemplar of d-t graph from raw data
4. Exemplar of ticker tape data
5. Exemplar of journal entries

Video or Image

1. Video of vehicle assembly
2. Video of vehicle and ticker tape in motion
3. Video of ultrasound range finder measuring d-t of scooter
4. Image of parts list and samples
5. Image of raw ticker tape
6. Image of range finder data from screenshot
7. Image of assembled vehicles
8. Image of motor closeup and gear
9. Image of gear and axle assembly
10. Image of motor mounting
11. Images (2) of motor electrical connections
12. Image of tools needed

5. **Tools**

1	pair of cutters, suitable for cutting wood (see image)
1	Glue gun with glue sticks

6. **Safety**

1. When using the cutters safety glasses should be worn by anyone using them or anyone in the vicinity.
2. The glue is VERY HOT (> 150 degrees) when it comes out of the glue gun, and can give severe burns when it contacts skin. Be very careful when using these.

Student Handout:

(SPH3U) **Inquiry-based Culminating Activity Using a Model Electric Car**

Strands and Units: Kinematics, Forces, Energy and Society, Electricity and Magnetism

Introduction to the project and activity

A model electric car will be built and its motion and performance analysed to summarise a wide range of concepts taught in this course. By the end of this project you will have collected the following data, analysed it for the given parameters, and performed the following tasks on it:

Data collected: time of acceleration, distance travelled, electric current and voltage used to accelerate car, mass of vehicle

Parameters Calculated: acceleration, final speed, power consumed, work done, mechanical energy produced, total vehicle friction

Tasks performed: time-distance graph made, five tangents derived from graph, slopes of tangents calculated, final velocity determined using slope

WATCH THE VIDEO

05:54 min

(//www.youtube.com/embed/-o2sFmJ7XaE?width=800&height=450&iframe=true)

RESOURCES

- National Electric Drag Racing Association Data (http://www.nedra.com/records-sp.html)
- Video with Electric Drag Racing Data (https://www.youtube.com/watch)
- Guardian Article Arguing Against Electric Cars (https://www.theguardian.com/environment/2017/aug/13/electric-cars-are-not-the-solution-pollutionwatch)
- US Department of Energy Pro Electric Car Article (https://www.energy.gov/eere/electricvehicles/electric-vehicle-benefits)
- hand drawn graph w tangents example 0.pdf (https://connex.stao.ca/sites/default/files/hand_drawn_graph_w_tangents_example_0.pdf)
- journal example 0.pdf (https://connex.stao.ca/sites/default/files/journal_example_0.pdf)
- ticker tape linear 0.jpg (https://connex.stao.ca/sites/default/files/ticker_tape_linear_0.jpg?width=4032px&height=3024px&iframe=true)
- tools 0.jpg (https://connex.stao.ca/sites/default/files/tools_0.jpg?width=4032px&height=3024px&iframe=true)
- different cars 0.jpg (https://connex.stao.ca/sites/default/files/different_cars_0.jpg?width=4032px&height=3024px&iframe=true)
- ticker tape accceleration 0.jpg (https://connex.stao.ca/sites/default/files/ticker_tape_accceleration_0.jpg?width=4032px&height=3024px&iframe=true)
- motor and gear wired 0.jpg (https://connex.stao.ca/sites/default/files/motor_and_gear_wired_0.jpg?width=4032px&height=3024px&iframe=true)
- car motor solder terminals 0.jpg (https://connex.stao.ca/sites/default/files/car_motor_solder_terminals_0.jpg?width=4032px&height=3024px&iframe=true)
- car motor wiring and gear 0.jpg (https://connex.stao.ca/sites/default/files/car_motor_wiring_and_gear_0.jpg?width=4032px&height=3024px&iframe=true)
- car battery holder 0.jpg (https://connex.stao.ca/sites/default/files/car_battery_holder_0.jpg?width=4032px&height=3024px&iframe=true)
- car closeup of gear and motor shaft 0.jpg (https://connex.stao.ca/sites/default/files/car_closeup_of_gear_and_motor_shaft_0.jpg?width=4032px&height=3024px&iframe=true)
- car parts photo 0.jpg (https://connex.stao.ca/sites/default/files/car_parts_photo_0.jpg?width=4032px&height=3024px&iframe=true)
- journal example 1.pdf (https://connex.stao.ca/sites/default/files/journal_example_1.pdf)
- sph3u culminating exemplar 0.pdf (https://connex.stao.ca/sites/default/files/sph3u_culminating_exemplar_0.pdf)
- 3u formula sheet july 2018 0.pdf (https://connex.stao.ca/sites/default/files/3u_formula_sheet_july_2018_0.pdf)
- sph3u inquiry project stao final 0.docx (https://connex.stao.ca/sites/default/files/sph3u_inquiry_project_stao_final_0.docx)

ELEMENT

- Inquiry (/expert-elements/inquiry)

(/classroom-catalysts) RETURN TO CATALYSTS (/classroom-catalysts)