**Subject area/course**: Science/Physics

**Grade level/band**: 11-12

**Task source**: Stanford Center for Assessment, Learning, and Equity (SCALE); author: Susan Schultz

**Designing Energy Efficient Vehicles**

**TEACHER'S GUIDE**

1. **Task overview**:

Student teams will research and define the terms “efficiency” and “energy efficient.” Based on their research, teams will design and build a vehicle. Then they will experimentally test the vehicle’s efficiency. After analyzing the initial data of the vehicle’s performance, teams will re-design, build, and test an “improved” version of their vehicle. Teams will use the experimental findings to make recommendations to the EcoPower car company CEO and engineering panel for releasing a new fleet of energy efficient vehicles in 2015.

IMPORTANT NOTES:

For clarity we are defining efficiency as (useful energy out)/(total energy in) and energy efficiency as "using less energy to provide the same service" (LBNL).

We encourage you to stick with cars as the vehicle of choice because it is a better fit with the context of the task. However, if you want to use boats as your vehicle that will work as long as you have a “track” or “waterway” for students to gather data and test the energy efficiency of their boat. We discourage the use of other types of vehicles.

1. **Aligned standards:**
2. **Common Core State Standards**

[CCSS.ELA-Literacy.RST.11-12.1](http://www.corestandards.org/ELA-Literacy/RST/11-12/1/) Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

[CCSS.ELA-Literacy.RST.11-12.2](http://www.corestandards.org/ELA-Literacy/RST/11-12/2/) Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

[CCSS.ELA-Literacy.RST.11-12.7](http://www.corestandards.org/ELA-Literacy/RST/11-12/7/) Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

[CCSS.ELA-Literacy.WHST.11-12.4](http://www.corestandards.org/ELA-Literacy/WHST/11-12/4/) Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

[CCSS.ELA-Literacy.WHST.11-12.5](http://www.corestandards.org/ELA-Literacy/WHST/11-12/5/) Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.

1. **Critical abilities**

Research: Conduct sustained research projects to answer a question (including a self-generated question) or solve a problem, narrow or broaden the inquiry when appropriate, and demonstrate understanding of the subject under investigation. Gather relevant information from multiple authoritative print and digital sources, use advanced searches effectively, and assess the strengths and limitations of each source in terms of the specific task, purpose, and audience.

Analysis of Information: Integrate and synthesize multiple sources of information (e.g., texts, experiments, simulations) presented in diverse formats and media (e.g., visually, quantitatively, orally) in order to address a question, make informed decisions, understand a process, phenomenon, or concept, and solve problems while evaluating the credibility and accuracy of each source and noting any discrepancies among the data.

Experimentation and Evaluation: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text. Evaluate hypotheses, data, analysis, and conclusions, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

Communication in Many Forms: Use oral and written communication skills to learn, evaluate, and express ideas for a range of tasks, purposes, and audiences. Develop and strengthen writing as needed by planning, revising, editing, and rewriting while considering the audience.

Use of Technology: Present information, findings, and supporting evidence, making strategic use of digital media and visual displays to enhance understanding. Use technology, including the Internet, to research, produce, publish, and update individual or shared products in response to ongoing feedback, including new arguments or information.

Interpersonal Interaction and Collaboration: Develop a range of interpersonal skills, including the ability to work with others, to participate effectively in a range of conversations and collaborations.

Modeling, Design, and Problem Solving: Use quantitative reasoning to solve problems arising in everyday life, society, and the workplace, e.g., to plan a school event or analyze a problem in the community, to solve a design problem or to examine relationships among quantities of interest. Plan solution pathways, monitoring and evaluating progress and changing course if necessary, and find relevant external resources, such as experimental and modeling tools, to solve problems. Interpret and evaluate results in the context of the situation and improve the model or design as needed.

1. **Next Generation Science Standards**

NGSS Disciplinary Core Ideas

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.

PS3.A. Definitions of Energy

PS3.B. Conservation of Energy and Energy Transfer

HS-PS3-1. 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.

HS-ESS3-4. Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.

Secondary to HS-ESS3-4. When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.

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| NGSS Science and Engineering Practices  *Defining the Problem*   * Defines a problem (design) statement that is adequately aligned to the intent of the problem.   *Developing and Using Models*   * Constructs accurate and labelled drawings, diagrams, or models to represent the process or system to be investigated. * Explains limitations and precision of model as a representation of the system or process.   *Planning and Carrying Out the Investigation*   * Proposes a design plan and explanation that adequately addresses the criteria, constraints, and intent of the problem. * Provides replicable procedures with descriptions of measurements, tools or instruments, and conducts adequate number of trials.   *Analyzing and Interpreting Data*   * Constructs accurately labeled spreadsheets, data tables, charts, or graphs to accurately summarize and display data to examine relationships between variables. * Accurately analyzes data using appropriate and systematic methods to identify patterns OR explain limitations of the data analysis (measurement error).   *Constructing Explanations and Designing Solutions*   * Uses adequate data to evaluate how well the design addresses the problem and explains an appropriate redesign of the original model or prototype.   *Communicating Findings*   * Accurately communicates clear and adequate findings consistent with the evidence and explains the implications and/or limitations of the investigation or design. |  |

1. **Time/schedule requirements:**

The following schedule is an estimate of the number of school days required for students to complete this task. Time requirements will vary based on grade level, schedule constraints, class size, class length, and academic readiness.

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| --- | --- | --- |
| **Day** | **What Students Need To Do** | **Product** |
| Day 1 | Intro: Get familiar with the task requirements, expectations, and due dates |  |
| Day 1 | Part 1: Research and define the term “energy efficient” | Lab Report |
| Days 2 - 8 | Part 2: Design and build an energy efficient vehicle |
| Part 3: Plan your investigation |
| Part 4: Test the performance of your vehicle |
| Part 5: Analyze and interpret your findings |
| Part 6: Modify (or re-build) and retest an “improved” vehicle |
| Part 7: Compare and contrast the performance of the “initial version” with the “improved version” of the vehicle (including calculations) |
| Part 8: Draw your conclusions |
| Day 9 | Part 9: Write a draft lab report with a list of recommendations for the EcoPower CEO and engineering panel |
| Day 10 | Part 10: Get feedback on your draft lab report |
| Day 12 | Part 11: Final report due |
| Day 14 | Part 12: Group Presentation | Oral Presentation |
| Day 15 | Reflect on learning | Essay |

1. **Materials/resources:**

Students will need:

* Access to the Internet for research
* Presentation software or poster-making materials
* Access to a variety of vehicle choices such as Mousetrap Racer, Rubber Band Powered Car, CO2 Car Kit, Solar Powered Car, Electric Car, Wind/Fan Car, Wind-Up Toys, Pull Back Car, or another type with your approval
* A “track” for testing their vehicles
* Tools such as coping saws, pliers, scissors, hot‐melt glue gun and glue, rulers, drill and bits, utility knife, etc.
* Materials for construction of the vehicles. Typical materials for cardboard vehicles with rubber band “motors” might include: several types of cardboard, several types of plastic drinking straws, metal wire and metal clothes hangers, craft (popsicle) sticks, many types of tape, several sizes of wooden dowel rods, several sizes of wooden craft wheels, various metal washers, metal can lids, old CDs, rubber bands, etc.
* *Criteria for Oral Presentations* document and *Lab Report Criteria* document

1. **Prior knowledge:**

Students will need to:

* Understand the concepts of motion, forces, and energy
* Be able to calculate efficiency
* Be familiar with design and building skills
* Be familiar with energy conversions

Students may have prior misconceptions. For example, they may think that:

* The principles and engineering that affect efficiency of the student models that are built in this task directly transfer to the production of real‐world vehicles
* The terms efficiency (a physics term) and energy efficiency (an every-day term) can be used interchangeably
* Vehicles in this task and in the real world extract a high percent of energy from the power source
* Conservation of energy does not apply to these systems since we cannot account for the energy at the end

1. **Connection to curriculum:**

This performance assessment could be used as a culminating activity for a unit on motion or energy in a physics or physical science course.

1. **Teacher instructions:**

Below is a comprehensive list of *suggested* ways to facilitate, organize, and scaffold student work, based on pilot implementation conducted by SCALE in real classrooms. You will, of course, need to choose which ideas meet the needs of your students, their previous experience with open-ended projects, and practicalities of your classroom/school, and adapt them accordingly.

You’ll notice that throughout we have tried to provide students with opportunities to make choices and take the lead in decision-making to complete the task. In this same vein, we encourage the use of peer-review and revision.

Students may need guidance in constructing a data table and calculating the efficiency of their car.

Possible Engagement Activities (The Hook)

Getting started:

* Ask students to investigate TV videos, Internet ads or print advertising for automobiles that are marketed as environmentally friendly or economical. Have them focus on the types of features that are cited that supposedly provide the vehicle with its fuel economy.
* Allow students to choose a favorite or interesting vehicle to research. Gather data on properties of the vehicle, but also note the characteristics that the car company touts as contributing to the efficiency of the vehicle. Try to establish if the properties might affect efficiency, or if it is strictly a sales pitch.
* Lead a student discussion as to which vehicle is more energy efficient: a school bus with 50 passengers or a Toyota Prius with 4 passengers. Have students think of energy efficiency in terms of the amount of energy (fuel) used to move each passenger a certain distance. Compare this definition of efficiency to the more standard physics concept of the percentage of energy that is transformed or extracted from a source.
* As the finite amount of fossil fuels is consumed, there are some different options. Ask students to consider the pros and cons of the following:
  + Reduce the use of fuels which will greatly affect our way of life
  + Convert to other sources of energy such as solar, biofuels, nuclear, etc.
  + Extend the life expectancy of fossil fuels by using them more efficiently

Introduce the Task

* After the introductory activity, review the task description and respond to any student questions.
* Suggest students design a template to be used to collect information and record references at the time data is being collected.
* Tell students that personal reflections should be written in a journal/log throughout the project.

Review Expectations

* Review the due dates/task timeline.
* Review expectations for working together in a group – the roles students should take on and the norms for behavior (for more details, see “Student Support” section).
* Allow students time to look at the assessment rubric(s). Clarify the criteria and respond to student questions.
* Explain that, as they work in their groups, they will be responsible for gathering information and making their own decisions. As the teacher, you will provide help/resources only when everyone in the group agrees that they need help or if there is information they can’t find themselves.

Part 1: Research and define energy efficient (Team Activity)

Students will research and share what they have learned about the terms “efficiency” and “energy efficient,” including:

* Through discussion come to an accepted class definition of energy efficiency. For example, for the model vehicles it might be defined in terms of the linear distance traveled using the energy stored in one rubber band, one mousetrap spring, or one CO2 canister.
* Compare this definition of energy efficiency to the physics definition of efficiency. Through discussion standardize the usages of both terms: energy efficiency and efficiency.
* Explore if our definition of efficiency is reasonable and what (if any) modifications might be beneficial.
* Identify the variable they will include in the design of their vehicle and explain how they think changing this variable will help them make a more energy efficient vehicle.

*Individual Task*: Students will need to summarize what they have learned from the research gathered by their team, refer to the *Lab Report Criteria* document, and write a content-specific introduction for their lab report.

Part 2: Design and build an energy efficient vehicle (Team Activity)

Vehicle choices include Mousetrap Racer, Rubber Band Powered Car, CO2 Car Kit, Solar Powered Car, Electric Car, Wind/Fan Car, Wind-Up Toys, Pull Back Car or another type with your approval. Please be aware that you do not need to provide all types of vehicles. A simple assortment of junk will suffice if that is all your budget will allow. Students will need to use the team’s knowledge about the factors affecting energy efficiency:

* Brainstorm the design features of their vehicle
* Make a drawing of their vehicle labeling all the parts and a list of materials needed to construct the vehicle
* Write a description of a vehicle explaining the features of the vehicle and a rationale for why this will make a more energy efficient vehicle
* Explain the connections between their vehicle design and Newton’s Laws of Motion
* Review their drawing and rationale with you for approval
* Build their vehicle and record any modifications that they make during the construction process
* Draw a picture or take a photograph of their vehicle

*Individual Task*: Students will need to write a summary of the design features for their vehicle and the rationale for why these features will produce a more energy efficient vehicle. Remind them to refer to the *Lab Report Criteria* document.

Part 3: Plan their investigation (Team Activity)

Students should plan how they are going to determine the energy efficiency of their vehicle. They should refer to *Lab Report Criteria* document when planning and writing their plan.

*Individual Task*: Students will need to record the procedures used to test their vehicle.

Note: Testing performance should be a measure of the distance the vehicle travels on a horizontal surface (carpet, gym floor, classroom tile, etc.) or on a “track”, along with collecting some information on the motion of the vehicle during the horizontal run (time/displacement data). This additional data will be necessary in order to describe and analyze the motion of the vehicle.

Part 4: Test the performance of the vehicle (Team Activity)

While conducting the experiment, students should take notes and record data including repeated trials. They should measure, calculate, and/or estimate an adequate number of the following characteristics of the vehicle so they can describe its performance when completing the course:

* Mass of the car
* Static friction
* Rolling or dynamic friction
* Average speed of the vehicle while completing the run on the course
* Final speed
* Typical acceleration during the first section (first meter, first quarter, etc.) of the run
* Amount of energy that can be stored or extracted from the vehicle’s “power” source

*Individual Task*: Students will gather all data from testing the performance of their vehicle and refer to the *Lab Report Criteria* document when writing this portion of their lab report.

Note: Descriptions of the vehicle’s motion (speeds, accelerations, forces, etc.) may be established using any available tools (tape timers, ultrasonic range finder, photo‐gates, stopwatches & tapes, etc.). The major emphasis here is to use physics tools to describe the motions and forces involved with a “real” vehicle. Obviously, as with any measurement, there will be a degree of error inherent to the attempt. Getting students to recognize the likely amount and source of the errors is important to this task.

Part 5: Analyze and interpret findings (Team Activity)

This is an essential part of the investigation. Students need to carefully examine the data they have collected and determine what they can say about the results of the investigation based on the evidence. Students will discuss the efficiency of their vehicle as well as the energy efficiency of their vehicle. Once again, students should refer to the *Lab Report Criteria* document.

*Individual Task*: Students will need to write the analysis and interpretation section of their lab report.

Part 6: Redesign, modify (or re-build), and test the performance of an “improved” vehicle (Team Activity)

Based on the performance and analysis of the data of their initial vehicle, students should:

* Select ONE feature to improve the performance of their vehicle
* Redesign their vehicle to try to improve the vehicle’s performance
* Build the “improved” version of their vehicle
* Clearly identify all of the variables to be studied (independent and dependent variables including controls, if applicable)
* Using the same course and methods, repeat their investigation to test their “improved” vehicle
* Be consistent in their methods in order to make a “fair” comparison

*Individual Task*: Students will write a summary of the re-design features of their “improved” vehicle and the rationale for why these features will produce a more energy efficient vehicle. Students should include these items in the materials and procedural sections of their lab report.

Part 7: Compare and contrast the performance of the two versions (Team Activity)

Students will compare and contrast the data from their initial and “improved” vehicles and include their analysis in their lab report.

*Individual Task*: Students will include this analysis in their lab report.

Part 8: Draw conclusions (Team Activity)

Students will review their analysis and interpretations of the data and write the conclusion section of the lab report. Students may be encouraged to compare their efficiency with vehicles in the real world.

*Individual Task*: Studentswrite the findings and address limitations in this section of the lab report.

Parts 9 - 11: Prepare draft and final lab reports (Individual Activity)

Students should:

* Get peer and/or teacher feedback on the draft
* Revise and submit a final lab report

Part 12: Present findings (Team Activity)

Students will make an oral presentation using visuals (PowerPoint or poster) to the EcoPower car company CEO and engineering panel. They will share the design and experimental findings of their vehicle and provide recommendations on how to improve the energy efficiency of vehicles. When preparing their presentation, students should refer to the *Criteria for Oral Presentations* document.

1. **Student support:**

Planning for Group Interaction

Student grouping can vary, but a group size of 2 or 3 seems to work well with this task. It may help group dynamics to assign students to specific roles (i.e., facilitator, materials manager, reporter, recorder, etc.) in order to promote student learning and/or utilize student skills. No matter what the team size, it is critical that each team keeps detailed records, and thus there must be at least one recorder for each team. As a classroom norm, encourage students to share their ideas, make a plan, and encourage all students to participate in the investigation.

This task is likely not the first group activity in your class. Yet, students need to be aware of the parallel nature of team and individual activities. You should make sure that students recognize that team research, experimentation, discussion, planning, and documentation are the jointly assembled basis for each student’s individual final report and possible presentation.

Possible Accommodations for Students with Special Needs

You will be the best judge of your students’ abilities but here are some suggested ways to revise the task depending upon your students’ needs:

* For students who may have difficulty conducting their own research, you can decide to provide research sources to the students to help them get started or provide students with abbreviated resource cards with the relevant information provided in text, graphs, diagrams, and other visuals.
* Provide a detailed graphic organizer to help students determine what information should be collected.
* Assign a specific type of vehicle to each group instead of letting them select it on their own.
* Walk students through the analysis of the data and provide sentence stems to help them write up sections of the analysis.
* Show examples of quality lab reports so students have a vision of what is expected for a quality product.

1. **Extensions or variations:**

There is a significant difference between the factors that make for an efficient vehicle in this task and those that matter for real world efficient vehicles. You may want to have students provide suggestions to the National Physics Teachers’ Vehicle Committee so students would recognize the many shortcoming of this model if upgraded to the real world.

1. **Scoring:**

Student work can be scored using the SCALE Science and Engineering Practices Rubric (9–12) and the SCALE Effective Communication Oral Presentation Rubric.

NOTE: Do not score students on the shaded (grey) dimensions of the Science and Engineering Practices Rubric (9–12). The shaded dimensions are not being assessed by this task.