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| Energy:Work (energy transfer) and Conservation of Energy |
| Science and Technology/Engineering |
| Grades 9-12 |
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| ***Description:*** *This unit incorporates Newton’s laws with the concepts of dissipative forces, conservative forces, work (transfer of energy), power, kinetic energy, potential energy and the conversion between kinetic and potential energy. There are seven lessons, including investigations and in some cases an Interactive Laboratory Experience, and word problems that each provide a context by which students can apply their learning and further deepen their understanding of a given concept. At the end of the unit, students will be expected to demonstrate their understanding of energy transfer and conservation of energy by building a mouse trap. It is anticipated that the entire unit, including the final performance assessment project, will take approximately 25 class periods.* |

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| **Assumptions** |
| (List knowledge or skills that students are expected to have before starting this unit. These should be pre-assessed before the unit begins so that remediation or differentiation needs can be identified and planned for.)Students are expected to known:Concepts, ideas and knowledge outlined in Massachusetts Department of Elementary and Secondary Education “Physical Science—Chemistry/Introductory Physics\* Concept and Skill Progressions,” November 15, 2010, pages 5-9 (Forces and Motion). Grade level: High School.Summary of these ideas follows:• how to define a “system” • how to differentiate between those entities that are part of a defined system and those entities that interact with the defined system but are not part of the system• the concepts of speed and velocity• the concept of acceleration• the concepts of force and net force• Newton’s 1st and 2nd laws (relationship between dynamics (forces) and kinematics (motion))• Newton’s 3rd law• how to draw schematic diagrams illustrating the forces acting during an interaction• that there exist three fundamental forces (electro-magnetic/weak, gravitational and nuclear)• that forces result from the interaction between like force fields (two objects that have mass interact through the gravitation field each object produces, objects that have charge interact through the electro-magnetic field each object produces and nuclear particles interact through the nuclear/quark fields that are associated with these particles).• how to compute the mutual gravitational force between an object *close* to the Earth’s surface and the Earth• how to compute the restoring force applied by a stretched and/or compressed Hooke’s law spring |

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| **Stage 1 Desired Results** |
| ESTABLISHED GOALS(these outcomes are related to state standards but are different as they anticipating changes based on both the state revision process and the NGSS)**New content/concept Ideas**G1. Investigate and explain the concepts of work, power, kinetic energy, potential energy and the relationship between them.G2. Analyze situations where work is performed on a system or object.G3. Summarize the general law of conservation of energy and compare and contrast the general principal of conservation of energy to the specific principal of conservation of total mechanic energy.G4. Evaluate situations to determine whether the general principal of conservation of energy holds true or the specific principal of total mechanic energy holds true.G5. Describe the transfer of energy that takes place in given situations.G6. Analyze situations where the principal of conservation of total mechanical energy holds true.G7. Use models of particle motion and fields to explain energy transfer in specific situations**Reinforced science and engineering practices (NRC Domain I.)** G8. Plan and carry out investigations – NRC I.3.G9. Analyzing and interpreting data – NRC I.4.G10. Use mathematical thinking to explain, analyze and model ideas and concepts – NRC I.5.G11. Construct explanations and design solutions to posed problems – NRC I.6.G12. Engage in argument from evidence – NRC I.7.G13. Obtaining, evaluating, and communicating information – NRC I.8.**Reinforced LA goals**G14. Write informative &/or explanatory texts, including the narration of scientific procedures &/or experiments, or technical processes ELA P79.G15. Write arguments focused on discipline specific content ELA P77. |  ***Transfer*** **T** |
| *Students will be able to independently use their learning to…*T1. Assess the energy use of physical systems.T2. Analyze mechanisms of cause and effect in designed systems based on physical principles. T3. Use principles of the physical world to assess designed products and systems based on social needs and wants.T4. Engage in sustained, complex and successful scientific inquiry. |
| ***Meaning*** |
| UNDERSTANDINGS **U***Students will understand that…*U1. Forces can be classified as either conservative or non-conservative.U2. Energy is a measure of the motion of an object (kinetic energy) and/or the measure of the location of an object, from a given reference point, within a force field (potential energy).U3. Work is the measure of the energy transferred into or out of a system/object.U4. Power is the rate at which energy is transferred into or out of a system/object.U5. Work is done on an object/system by a force whenever the object has a component of its displacement in the direction of the force.U6. Energy cannot be created or destroyed, but energy can be transferred and transformed between and within systems.U7. Work done by ALL forces acting on a system is equal to the change in kinetic energy of the system (Work-Energy Theorem).U8. Work done by all external forces and all non-conservative forces acting on a system is equal to the change in total mechanical energy of a system.U9. If there are no external forces and no non-conservative forces acting on a system, then the change in kinetic energy of the system is equal to the negative change in potential energy of the system. This can also be expressed as conservation of total mechanical energy (kinetic plus potential).U10. Engineering design often entails among other factors product definition, constraint criterion, research, modeling, trade-offs, analysis of data, iteration, ability to work in teams and communicating ideas to a 3rd party. | ESSENTIAL QUESTIONS **Q**EQ1. Where does energy come from?EQ2. How can energy be measured?EQ3. How do I know when energy is transferred? EQ4. How do we use energy transfer to design systems/products to benefit society and /or meet specific needs? |
| ***Acquisition*** |
| *Students will know…* **K**K1. The causal agent for the transfer of energy (work) is the result of force acting over a displacement (actually the component of the force in the direction of the displacement (e.g., W= **F**average •**∆d**).*K2. Power is the rate at which work is performed and is proportional to the work done and inversely proportional to the time it takes to perform the work (e.g., Pavg = Work/∆t.). Optional*K3. The relationship between energy of motion (kinetic energy), mass and speed (qualitatively and quantitatively – larger speed 🡺 greater KE and KE ~ v2; large mass 🡪 greater K and KE ~ m)K4. Potential energy can be classified based on the type of force field in which an object is placed (e.g. electro-magnetic potential energy (chemical potential energy and elastic potential energy are specific examples of electro-magnetic potential energy), gravitational potential energy, and nuclear potential energy).K5. Energy can be transferred and transformed between and within potential energy and kinetic energy.K6. Conservation of energy means the total change of energy in any system is equal to the sum of the energy transferred into the system plus out of the system. K7. The change in potential energy of an object can be determined directly from the work done by the force field when an object is displaced in the field (e.g., ∆PE = **- F**field,avg • **∆s**).K8. The change in gravitational potential energy for an object displaced in the near Earth gravitational field (∆PE=(mg)∆h) and the change in elastic (electromagnetic) potential energy due to a compressed/stretched spring (∆PE=.5ks22-.5ks12) follows directly from the principle that ∆PE = **- F**field,avg • **∆s**.K9.A force field gives rise to a conservative force if the work required to change an object’s position (displace the object) within the force field is the same no matter the physical path taken to make the displacement.K10. When only conservative forces act on a system, ∆KE = -∆PE or Total Mechanic Energy remains constant over time.K11. Know key terms (conservative force, non-conservative force, dissipative force, external force, internal force, work (transfer of energy), potential energy, kinetic energy, gravitational potential energy, elastic potential energy, Hooke’s law spring, elastic and inelastic interactions, conservation of total mechanical energy). | *Students will be skilled at…* **S**S1. Choose appropriate technology to study energy.S2. Use the formula W = **F**average **•∆d** to analyze and compute the work done on an object by a force.*S3. Use the formula Pavg = W/∆t to compute the average power for a given situation. Optional*S4. Use the formula KE=.5mv2 to compute the kinetic energy of an object.S5. Use the formula PE=(mg)h to compute the potential energy of the Earth-object system when an object is located near the Earth’s surface (where h is the distance from an arbitrary reference point often chosen to be the Earth’s surface or the closes point to the Earth’s surface an object gets for a specific problem).S6. Use the formula PE=.5ks2 to compute the potential energy of a Hooke’s law spring (where s is the stretch or compression of the spring from its natural length).S7. Use the strategy of computing the area under a force-displacement graph to determine the work done by a force.S8. Use the formula Wexternal + Wnon-conservative = ∆KE + ∆PE to analyze and solve problems of energy transfer.S9. Articulate how energy is transferred between systems.S10. Use the concept of conservation of energy to predict and describe system (position and speed) behavior.S11. Use data gathered through experiments to analyze and draw conclusions.S12. Use evidence and scientific and mathematical reasoning to communicate experimental results and to make claims.  |
| **Stage 2 - Evidence** |
| **Evaluative Criteria** | **Coding** | **Assessment Evidence** |
| See “Standards & Criterion for Success” in third column. | G1, G2, G4, G5, G6, G8, G9, G10, G11, G12, G13, G14, G15U1, U2, U3, U5, U6, U7, U9, U10K1, K3, K4, K5, K6, K7, K8, K10, K11S1, S2, S4, S5, S8, S9, S10, S11, S12 | **Performance Assessment – Mousetrap Car Energy Transfer Project** **PT****Goal:** Construct a Mousetrap car that uses a spring as a power source and meets specified construction and performance criterion. **Role:** Engineering team working for the “Extreme Toys R’US” company.**Audience:** The product you are designing is targeted for sale to boys and girls between the ages of 9 and 13.**Scenario:** The CEO has assigned your engineering team along with two other engineering teams the task of deigning a “Mouse Trap” car for sale to boys and girls ages 9-13. The teams are given specific performance criterion and design/construction criterion. **Performance criterion** are: (1) Your vehicle is to maximizes the conversion of potential energy to kinetic energy at launch (e.g., |∆KElaunch/∆PElaunch| is as close to 1 as possible); (2) minimizes the net frictional force that acts on the car following launch (e.g., |∆KEcoast/∆xcoast| is as close to 0J/m or 0N as possible) and (3) will move at least 1-meter following launch. **Design/construction criterion** are: (1) The total cost of the car must not exceed $20; (2) the energy source for the “Mouse Trap” car is one standard Mouse Trap supplied by the hardware division of Toys R’US; (3) the vehicle must be able to fit into a rectangular container no larger than 40 cm by 15 cm by 15 cm; (4) the car can not have more than four wheels; (5) company safety and (6) team work protocols must be followed during all engineering design phases of the work; and (7) the vehicle evaluation’s will be partially determined by the aesthetics rating of two separate consumer focus groups (one comprised of all males and one comprised of all females within the target audience age span). The team that produces a vehicle that meets all design/constructive criterion (1) through (4) and has the highest score on the “Standards & Criterion for Success” rubric found below will be awarded an end of year “product development” bonus.**Product:** • A working vehicle.• A written “performance report” tracing ***qualitatively*** and ***quantitatively*** the transfer of energy that takes place during launch and during the subsequent coast.• A written “design manual” outlining considerations for constructing a Mousetrap car that will meet the specified construction criterion (cost constraints, one standard Mousetrap, size constraints, no more than 4-wheels) and performance criterion (maximize transfer of energy from the Mousetrap mechanism to the kinetic energy of the car at launch and minimize the net frictional force acting on the car following launch). The design manual will also include schematic diagram(s) illustrating all major components of the final working vehicle.**Standards & Criterion for Success:** The project will be assessed on the following criteria:*Miscellaneous (total of 20 points)*• Vehicle does not meet all design criterions (1) through (4) – NOT eligible for bonus and -20 pts.• Vehicle works and following launch moves forward at least 1-meter – score of 0 or 5 pts.• Average aesthetics rating of the two consumer test groups - maximum score of 5 pts.• Design team follows company safety rules throughout project – maximum score of 5 pts.• Design team follows company team work practices throughout project – maximum score of 5 pts.*Performance Report (total of 60 points)*• Maximizes energy transfer during launch - <35% = 0 pts.; ≥35% 2 pt.; ≥40% = 4 pts.; ≥45% = 6 pts.; ≥50% = 8 pts.; ≥60% = 10 pts.• Clarity of written evidence in support of energy transfer claim – 25 pts.• Minimizes net frictional force during coast (based on comparison between all engineering teams) – maximum score of 10 pts.• Clarity of written evidence in support of frictional force claim – 15 pts*Design Manual (total of 20 points)*• Clarity and completeness of schematic diagram(s) of car and key components – maximum score of 10 pts.• Clarity and completeness of discussion of design considerations – maximum score of 10 pts.• Bonus Points: Car travels 5 m or more – bonus of 5 points Car travels the furthest of all tested cars – bonus of 5 points  |
|  |  | **OTHER EVIDENCE****•** Pre-test of requisite knowledge **(**Force Motion Concept Inventory) – formative assessment**•** Pre-test of new knowledge and ideas embedded in Energy Unit (ECI) – formative assessment**•** Post-test of new knowledge and ideas embedded in Energy Unit (ECI) – summative assessment**•** Reports from Lessons 2 - 6 investigations – formative/summative assessment• Physics Boxes from Lessons 2-6 – formative/summative assessment• Curriculum Embedded Performance Assessment (CEPA) from Lesson 7 (see details for assessment above and in support documents provided for Lesson 7) – summative assessment• Optional: Other teacher generated follow up extensions (i.e., reflective journals, traditional homework, quizzes, tests, etc.) supporting Lessons 2 through 6 – formative/summative assessments |

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| **Stage 3 – Learning Plan** | **Requisite Knowledge, Pre- or Mis-conceptions** |
|  *Summary of Key Learning Events and Instruction* **L****Minimum Suggested Equipment List (**over and above usual standard science classroom supplies (e.g., meter sticks, rulers, stop watches, assorted masses, calculators, etc.**))****•** 1 computer(with free data collection software) and projection capabilities.**•** 1 sonic detector (~$100)**•** 1 force probe and interface box (~$175)**•** 1 cart and track system (~$250)**•** 1 ticker tape time (~$140)**•** 1 Hooke’s law spring (~$30)**Ideal Suggested Equipment List**• 1 computer with projection capabilities.• 8 student lab group computer stations (with free or more robust paid data collection capabilities)• 8 sonic detectors• 8 force probes and interface boxes• 8 cart and track systems**•** 8 Hooke’s law springs**•** 2 ticker tape timers**Alternative Equipment List**• ticker-tape timers can be used to replace sonic detector (consequence is lost real time feedback and increased time to analyze data).• spring-scale can be used to replace digital force probe (consequence is increased variability of results)• smooth flat table can replace track system (consequence is increased variability of results)• photo-gate can replace sonic detector for some experiments | **Potential Misconceptions:**• Energy gets used up or runs out. • Something not moving can't have any energy. • A force that acts on an object does work even if the object does not move. • Energy is destroyed in transformations from one type to another. • Energy can be recycled. • Gravitational potential energy is the only type of potential energy. • When an object is released to fall, the gravitational potential energy immediately becomes all kinetic energy. • Energy is not related to Newton's laws. • Energy is a force.• Students may believe that energy is truly lost in many energy transformations.• Work is energy.**Pre Test of Requisite Knowledge:**FMCI (Force Motion Conception Inventory)**Pre/Post Test of New Knowledge:**ECI (Energy Conception Inventory)**Learning Events** (estimated time for unit is between 25 and 30 class periods)**Pre-Test of Requisite Knowledge:** Force Motion Concept Inventory (1 day)[Depending on results – time for “re-teaching” (0 to 3 days)]It is suggested that this pre test be given a week prior to the start of this unit (to give a separation in time between the two pre-tests and to allow for “re-teaching” prior to starting the new unit.**Unit Pre-Test** (½ day)***Lesson Plan #1*** (1½ class periods)1. Brainstorming activity using the four Essential Questions as catalyst (e.g., word splash, KWL, etc.). ½ class period.
2. Watch video on energy and energy transfer and transformation and follow up discussion relating what was viewed to previous brainstorming discussion. ½ class period.
3. Draft concept map on key terms. ½ class period.

***Lesson Plan #2*** (3 class periods)1. Investigation L2: Work (common sense definition versus scientific definition). 2 class periods

Discussion and extensions. 1 class periods***Lesson Plan #3 - Optional*** (3 class periods – this is the appropriate place in the unit for the lesson on power, however this lesson is not necessary for the integrity of the Energy Unit as a whole).1. Investigation L3: Power (burning off the Calories in a Snicker’s bar). 2 class periods

Discussion and extensions. 1 class period***Lesson Plan #4*** (3 class periods)1. Investigations L4: Work and Kinetic Energy Connection. 1.5 class periods

Discussion and extensions. 1.5 class periods.***Lesson Plan #5*** (4 class periods)1. Investigation L5: Work and Potential Energy Connection. 2 class periods.

Discussion and extension (include qualitative discussion/demo using spring). 2 class periods.***Lesson Plan #6*** (5 class periods)1. Investigation L6: Conservation of Total Mechanical Energy. 2 class periods.

Discussion, demos (i.e., Newton’s Cradle) and extensions. 1 class period.Discussion and demonstration looking at situations where Total Mechanical Energy is conserved and not conserved with related topics (i.e., energy efficiency) 1 class period.1. Discussion on topics related to “real world” (i.e., power plants, gas motors, types of light bulbs, etc.). 1 class period.
2. Revisit concept map on key terms. 1 class period.

***Lesson Plan #7*** (5 class periods)1. Performance Assessment – Mouse Trap Car. 5 class periods.

Read articles re: hybrid cars and recovering “lost “energy.***Unit Post Test*** (1 class periods)Optional Extension: Research project that relates big science ideas, content, skills to a real world problem such as “Are we running out of energy?” |
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| Adapted from Understanding by Design 2.0 © 2011 Grant Wiggins and Jay McTighe  Used with Permission July 2012 |

Content Area/Course: **Physics** Grade(s): **9-12** Date: Time (minutes or hours): 1 ½ class period (~1.5 hr.)

Unit Title: **Energy**

Lesson Title: **Lesson 1- What Do You Know?**

Essential Question(s):

EQ1 - Where does energy come from?

EQ2 – How do we measure energy?

Standard(s)/Unit Goal(s) to be addressed in this lesson: G1, G2, G5

Assumptions about what students know and are able to do coming into this lesson (including language needs):

Concepts, ideas and knowledge outlined in Massachusetts Department of Elementary and Secondary Education “Physical Science—Chemistry/Introductory Physics Concept and Skill Progressions,” November 15, 2010, pages 5-9 (Forces and Motion). Refer to unit plan assumptions.

Where this lesson comes in a sequence: Lesson #1 of 7

 Beginning Middle End

Outcome(s)

*By the end of this lesson students will know and be able to:*

The primary goal of this lesson is to allow students to share with each other and the instructor what they (the students) know/believe about the concept of energy and topics related to energy. In this lesson, students engage in a general brainstorming session, watch a film related to energy, view several demonstrations related to energy and dialog about their pre-conceptions concerning ideas on energy. Following the class demonstrations, videos and dialog students develop a pre-unit draft concept map.

Instructional Resources/Tools (What does the complexity of these texts or sources demand of the students?)

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| Word SplashDemos – Examples: Swinging Pendulum; Spring Gun Firing a Projectile; A Ball Thrown Straight Upward; Newton’s Cradle; Colliding Cars on a Track; etc. Videos – Examples: Pendulum clip MIT: <http://video.mit.edu/watch/hooks-law-pendulum-demo--10-2936/>;Teachers Domain: Energy in Roller Coaster Ride: <http://www.pbslearningmedia.org/content/hew06.sci.phys.maf.rollercoaster/> Concept map  |

Anticipated Student Preconceptions/Misconceptions

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| **Potential Mis-conceptions:**• Different types of energy are not related.• Something not moving can't have any energy. • A force that acts on an object does work even if the object does not move. • Energy is not related to Newton's laws. • Energy is a force.• Work is energy. |

Assessment

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| Pre-assessment/ Formative  | Summative (optional) |
| Class word splashDraft pre-unit student energy concept map activity  |  |

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| Lesson Sequence and Description | *This column may be used to suggest/provide*:**Word splash**When doing the word splash, the teacher should preface the exercise by saying there are no right or wrong answers. The purpose here is to elicit ideas from students about their ideas surrounding the concept of energy. Whether the ideas are factually accurate or not is less important than the process of bringing out students' background knowledge and encouraging them to make connections between the upcoming classroom activities and the real world. With this goal in mind, it is essential that the teacher not label terms and ideas students offer as "right" or "wrong," but instead encourage students to go along with the exercise so we can later come to new conclusions together as a group.**Steps to Constructing a Concept Map**1. Pair students in groups of two or three.
2. Students group the words from the Word Splash along with any additional words they think are relevant by similar characteristics.
3. Students arrange terms from general to most specific.
4. Students transfer words to flip chart paper creating hierarchies.
5. Students draw directional arrows linking terms. Cross-linking is required.
6. Students write the relationships between each term above the linking arrows.

Students will have the opportunity in lesson plan 6 to revise their concept map.  |
| *Please provide enough information and details so the teacher can deliver the lesson.***IMPORTANT** **NOTE**: Do NOT assign any reading about this unit (energy) until AFTER Lesson #2 Investigation “Work.” Lesson #1 students engage in a general brainstorming session where students dialog about their pre-conceptions of energy, watch a film on energy, view demonstrations and develop a pre-unit draft concept map. 1. **Word Splash (~25 minutes)**

Teacher: “Energy is our topic … what do you know? Before we open up to a general class dialog, each of you write on a piece of paper at least four words or short 2- or 3- word phrases that come to mind when you think about the concept of energy.” (5-minutes)Teacher elicits from the students their words and/or short phrases and writes them on the board and/or if a computer with internet connectivity is available, the teacher should have a student enter the words/short phrases into a word cloud application such as Wordle (<http://www.wordle.net>). Students are NOT asked at this time to define the terms they wrote down. Students are instructed to write words into their notebook (or if possible a printout of the “word cloud” is distributed). This word list will form the nucleus of words and concepts for the development of the students’ concept map. (20 minutes).1. **Demostrations** (teacher choice… see suggestions below)

Place a heavy pendulum bob suspended from the ceiling. It may be a baseball or even as heavy as a bowling ball. Extend the pendulum bob to the tip of your nose. Prior to releasing the bob, ask the students to predict what will happen? Provide guidance for them to include comments on speed, acceleration and pendulum bob height from the floor. Have the students record their predictions in their notebook and to share their thoughts with a neighbor. Perform the demo and elicit student comments about what they observed. Also ask students to comment on how their observations compared to what they predicted.1. **Video** (teacher choice… see two suggests below)

Pendulum clip MIT: <http://video.mit.edu/watch/hooks-law-pendulum-demo--10-2936/>;Teachers Domain: Energy in Roller Coaster Ride: <http://www.pbslearningmedia.org/content/hew06.sci.phys.maf.rollercoaster/>1. **Concept Map** (start this toward the end of day 1)

Just spend enough time on this during day 1 so students can productively continue working on this activity for homework. Spend perhaps an additional 20 to 30 minutes on construction and discussion of the students’ concept maps during day 2. Immediately following completion of the concept map, introduce Lesson 2: “Work.” Students will keep their concept map in their notebook and should revisit the concept map following each Lesson of the unit. Students can make iterative modifications to their concept map and all students will be asked to make a major revision or re-writing of their concept map following Lesson #6. |
| *Extended Learning/Practice (homework)* **Homework**Students, if possible with their concept map partners, expand the word/phrase list from the Word Splash activity. DO NOT ask the students to do any reading or to consult any resources for this homework assignment. |
| Closure*Review outcomes of this lesson:* Outcomes for this lesson are related to “engagement” and allow students to share with each other and the instructor what they (the students) know/believe about the concept of energy and topics related to energy. *Preview outcomes for the next lesson:* In Lesson #2, the students’ will develop an understanding of the scientific definition of work and how it differs from the “common sense” definition  |

Teacher Reflection (to be completed after lesson)

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| What went well in this lesson?Did all students accomplish the outcome(s))? What evidence do I have?What would I do differently next time? |

Content Area/Course: **Physics** Grade(s): **9-12** Date: Time (minutes or hours): 3 class period (~2.5 hrs)

Unit Title: **Energy**

Lesson Title: **Lesson 2 - Work**

Essential Question(s) to be addressed in this lesson:

Standard(s)/Unit Goal(s) to be addressed in this lesson: G1, G2, G5, G9, G12, G13

Assumptions about what students know and are able to do coming into this lesson (including language needs): Same as prescribed in Lesson #1 plus understanding, knowledge and skills acquired in Lesson #1.

Where this lesson comes in a sequence: Lesson #2 of 7

 Beginning Middle End

Outcome(s)

*By the end of this lesson students will know and be able to:*

K1: The causal agent for the transfer of energy (work) is the result of force acting over a displacement (actually the component of the force in the direction of the displacement (e.g., W= **F**average •**∆d**).

S2: Use the formula W = **F**average **•∆d** to analyze and compute the work done on an object by a force.

S7. Use the strategy of computing the area under a force-displacement graph to determine the work done by a force.

S9. Articulate how energy is transferred between systems.

S11. Use data gathered through experiments to analyze and draw conclusions.

S12. Use evidence and scientific and mathematical reasoning to communicate experimental results and to make claims.

Instructional Resources/Tools (What does the complexity of these texts or sources demand of the students?)

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| **•** Investigation L2: Work – Common Sense Definition versus Science Definition• Readings - FOLLOWING the Investigation readings should be assigned from any introductory physics text chapter/section dealing with the scientific definition of work.• Problems: 2.1 - 2.4 (required); 2.5 and 2.6 (optional). |

Anticipated Student Preconceptions/Misconceptions

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| **Potential Mis-conceptions:**• Something not moving can't have any energy. • A force that acts on an object does work even if the object does not move. • Energy is not related to Newton's laws. • Energy is a force.• Work is energy. |

Assessment

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| --- | --- |
| Pre-assessment/ Formative  | Summative (optional) |
| Investigation L2., class discourse, Problems 2.3 & 2. 4. |  |

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| Lesson Sequence and Description | *This column may be used to suggest/provide*:* The students should have an understanding of the relationship between kinematic variables and to have an understanding of Newton’s 1st, 2nd, and 3rd laws
* The actual investigation should take between 50 minutes and 90 minutes.
* Be guided by the philosophy exposed in the attached ILE/ILD (Interactive Laboratory Experience/Interactive Lecture Demonstration) document with special attention to promoting individual intellectual risk taking and discourse among students.

(See Appendix I) |
| *Please provide enough information and details so the teacher can deliver the lesson.*This lesson follows Lesson #1. In Lesson #1 students engaged in a general brainstorming session where students dialoged about their pre-conceptions of energy, watched a film on energy and develop a pre-unit draft concept map. Lesson #2 begins with Investigation L2. DO NOT have students read about the scientific definition of work prior to the investigation. Students through this activity will confront the difference between the “common language” definition of the word “work” and the formal scientific definition of work. The students’ will develop an understanding of the scientific definition of work and how it differs from the “common sense” definition by performing the investigation and during discourse between students and guided questioning and probing by the instructor. Begin Investigation L2 with a brief general statement of what the students are about to investigate (i.e., “We will use this investigation to look at our common sense definition of the scientific tem “work” and compare and contrast that definition with the scientific definition for work.”) DO NOT assign reading on the concept of work or give a formal scientific definition of work prior to the students engaging in the investigation. During the activity the teacher ‘s role is to facilitating on-task behavior, answer “clarification” questions, probe student thinking, remind students of past knowledge, and to respond to student questions, as best as possible, with guided questions (i.e., the discourse can be generally characterized as “Socratic.”). Leading questions from the teacher may stretch the student’s thinking significantly or may contain hints and only require a small leap of thinking from the student. The instructor will use their best judgment based on the needs of their individual students and the students’ ability to tolerate potential frustration during this back-and-forth questioning.Once the investigation is completed the instructor should lead a discussion to make sure the students have responded to the investigation correctly and that the students within the class all have a comfortable understanding of this new concept (i.e., work done by a force). All students should do Problems 2.1 – 2.4. |
| *Extended Learning/Practice (homework)*Problems 2.5 and 2.6 are optional extensions (please look at them to determine if they would be appropriate for your students). |
| Closure*Review outcomes of this lesson:* K1: The causal agent for the transfer of energy (work) is the result of force acting over a displacement (actually the component of the force in the direction of the displacement (e.g., W= **F**average •**∆d**).S2: Use the formula W = **F**average **•∆d** to analyze and compute the work done on an object by a force.S7. Use the strategy of computing the area under a force-displacement graph to determine the work done by a forceS9. Articulate how energy is transferred between systems.S11. Use data gathered through experiments to analyze and draw conclusions.S12. Use evidence and scientific and mathematical reasoning to communicate experimental results and to make claims.*Preview outcomes for the next lesson:*Students will extend their understanding of work to power – the rate in time in which work is done. |

Teacher Reflection (to be completed after lesson)

|  |
| --- |
| What went well in this lesson?Did all students accomplish the outcome(s))? What evidence do I have?What would I do differently next time? |

**Investigation #L2:**  Work

**I. Experiment - Common Language Definition of Work versus Scientific Definition of Work**

i. Lift your physics book slowly and with a steady speed from the table top to a height of approximately one-half meter above the table.

ii. Lift two physics books placed one on top of the other with the same slow steady speed from the table top to a height of approximately one-half meter above the table.

iii. Lift the two books placed one on top of the other with the same slow steady speed to a height of approximately one meter above the table.

iv. Hold the two physics books out in front of you at about waist level for 180 seconds.

**II. Individual Predictions**

1a. Look at experiments (i) and (ii). **Claim:** In which case did the force you exerted on the book do more work?

1b. **Evidence (reasoning):** What was your rationale for your claim?

2a. Look at experiments (ii) and (iii). **Claim:** In which case did the force you exerted on the book do more work?

2b. **Evidence (reasoning):** What was your rationale for your claim?

3a. Look at experiments (i) and (iv). **Claim:** In which case did the force you exerted on the book do more work?

3b. **Evidence (reasoning):** What was your rationale for your claim?

**III. Small Group Discussion**

Share your results with your laboratory partners and dialog about your various claims and evidential statements.

**IV. Comparing a Common Language Definition to a Scientific Definition of Work.**

Layman's Definition: Most "layman" when asked about a definition for work answer with "it measures the effort" it takes to get the job done (to lift the single book, the two books, to hold the book at waist level).

Scientific Definition: The work done is equal to the dot product between the average force acting on an object and the displacement of the object while the force is acting (i.e., multiply the component of the force that acts in the direction of the displacement times the displacement of the object while the force is acting).

Although the intuitive definition and the more formal definition of work agree quite well in many cases, the two definitions diverge greatly for many other cases.

4a. **Claim:** Of the four experiments performed above, which experiment illustrates the divergence between the "layman" and scientific definitions most strikingly?

4b. **Evidence:** State your reasoning for the claim you made.

5a. **Claim:** Of the four experiments, using the scientific definition of work, which experiment illustrates the job where the force you exerted on the book did the least amount of work?

5b. **Evidence:** State your reasoning for the claim you made.

6a. **Claim:** Of the four experiments, using the scientific definition of work, which experiment illustrates the job where the force you exerted on the book did the most amount of work?

6b. **Evidence:** State your reasoning for the claim you made.

7a. **Claim:** Can the work done by a force ever be positive?

7b. **Evidence:** State your reasoning for the claim you made, and if you answered "yes", then also give an example illustrating your point of view.

8a. **Claim:** Can the work done by a force ever be negative?

8b. **Evidence:** State your reasoning for the claim you made, and if you answered "yes", then also give an example illustrating your point of view.

9. Calculate the work done by the force you exerted on the book in each of the four experiments performed. Start with the formula for the definition of work, show substitution with units and then your answer for each case with appropriate units. You may use the force plate to weigh the objects or an electronic balance to find the mass of the objects to then calculate their individual weights.

 Experiment (i). Experiment (ii).

 Experiment (iii). Experiment (iv).

 **PROBLEM 2.1**

A 2.0 kg object is pulled in the horizontal direction with a force of 6.0 N and is observed to move at a ***constant speed*** of 3.0 m/s. (a) Draw a force diagram illustrating all forces acting on the object as it slides. The object is observed to move with this constant speed for 8.0 m. (b) Determine the work done by each force that acts on the object. (c) Determine the net work (total energy transferred to or from the object) by the net force while the object is observed to move a distance of 8.0 m. Your solution must contain a clear explanation of the physics principal(s) used, include appropriate use of units and an answer with units.

**PROBLEM 2.2**

A 4.0 kg object is sitting at rest on a frictionless surface. The object is then acted on by a force that is directed parallel to the ground. The force-position graph for this motion is shown. (a) Draw a force diagram on the mass being acted on. (b) Determine the work done on the object by the applied force. Your solution must contain a clear explanation of the physics principal(s) used, include appropriate use of units and an answer with units.

 **PROBLEM 2.3**

A pitcher throws a ball having a mass of .50 kg toward the plate. As the ball begins to cross the plate at a speed of 35 m/s the batter swings in a plane 10 degrees up with respect to the ground. The bat exerts an average force of 450 N over a distance of 25 cm both in the direction 10 degrees up w.r.t the ground. (a) Draw a force diagram showing the forces acting on the ball. (b) Determine the work done by the force of the bat acting on the ball. Your solution must contain a clear explanation of the physics principal(s) used, include appropriate use of units and an answer with units.

**PROBLEM 2.4**

A force-position graph for a Hooke’s law spring of length 1.2 m is shown to the right (the origin is taken at the location where the spring is fixed to a bumper). The maximum this spring can be compressed is to a final length of .40 m (at this compression all the coils are touching). The spring is compressed by .70 m from its natural length. A 4.0 kg object is placed against the now compressed spring and then the spring is released to push against the mass. As the spring returns to its natural length, the mass is launched (a) Draw a force diagram on the mass while the spring is pushing it. (b) Determine the work done by the spring on the mass while the mass is being pushed by the spring. Clarity of your written communication and explaining the physics principal(s) behind your thinking is a required part of the solution.

 **PROBLEM 2.5** (Optional)

You are pulling your little sister on a sled across the rough snow pack. The sled along with your sister has a mass of 45 kg and the frictional force on the rails of the sled is 150 N. You pull on a rope attached to the front of the sled with a constant force of 210 N at an angle of 30.0 degrees up from the horizontal. As you continue to pull the sled, the sled is observed to move forward a distance of 2.5 m. (a) Draw a force diagram showing the forces acting on the sled/sister system. (b) Determine the work done by each of these forces. (c) Determine the net work done on the sled/sister system. (d) Using Newton’s laws, determine the final velocity of the sled system (we will look at this solution again once we study the Work-Energy Theorem). Your solutions must contain a clear explanation of the physics principal(s) used, include appropriate use of units and an answer with units.

 **PROBLEM 2.6** (Optional)

An object of mass 150 g is set in circular motion on a frictionless tabletop. The object is attached to the center point of the circle of radius .80 m by a “massless” cord. A force gauge placed to measure the tension in the cord reads 22 N. (a) Draw a force diagram showing the forces acting on the 150 g object while it is moving in the circular path. (b) Determine the work done by each force that acts on the object while the object moves in this circular path. Your solution must contain a clear explanation of the physics principal(s) used, include appropriate use of units and an answer with units.

Content Area/Course: **Physics** Grade(s): **9-12** Date: Time (minutes or hours): 3 class period (~2.5 hrs)

Unit Title: **Energy**

Lesson Title: **Lesson 3 - Power**

Essential Question(s) to be addressed in this lesson:

Standard(s)/Unit Goal(s) to be addressed in this lesson: G1, G2, G5, G9, G12, G13

Assumptions about what students know and are able to do coming into this lesson (including language needs): Same as prescribed in Lesson #2 plus understanding, knowledge and skills acquired in Lesson #2.

Where this lesson comes in a sequence: Lesson #3 of 7

 Beginning Middle End

Outcome(s)

*By the end of this lesson students will know and be able to:*

K1: The causal agent for the transfer of energy (work) is the result of force acting over a displacement (actually the component of the force in the direction of the displacement (e.g., W= **F**average •**∆d**).

K2. Power is the rate at which work is performed and is proportional to the work done and inversely proportional to the time it takes to perform the work (e.g., Pavg = Work/∆t.)

S2: Use the formula W = **F**average **•∆d** to analyze and compute the work done on an object by a force.

S3. Use the formula Pavg = W/∆t to compute the average power for a given situation.

S7. Use the strategy of computing the area under a force-displacement graph to determine the work done by a force.

S9. Articulate how energy is transferred between systems.

S11. Use data gathered through experiments to analyze and draw conclusions.

S12. Use evidence and scientific and mathematical reasoning to communicate experimental results and to make claims.

Instructional Resources/Tools (What does the complexity of these texts or sources demand of the students?)

|  |
| --- |
| **•** Investigation L3: Power – Snickers Laboratory• You may either have students read about power before, during or after the investigation.• Problems 3.1 and 3.2 |

Anticipated Student Preconceptions/Misconceptions

|  |
| --- |
| **Potential Mis-conceptions:**• Something not moving can't have any energy. • A force that acts on an object does work even if the object does not move. • Energy is not related to Newton's laws. • Energy is a force.• Work is energy.• Power is a force• Students may believe that energy is truly lost in many energy transformations. |

Assessment

|  |  |
| --- | --- |
| Pre-assessment/ Formative  | Summative (optional) |
| Investigation L3, expository and dialog, Problems 3.1 and 3.2 |  |

|  |  |
| --- | --- |
| Lesson Sequence and Description | *This column may be used to suggest/provide:** The students should have an understanding of the relationship between kinematic variables. an understanding of Newton’s 1st, 2nd, and 3rd laws and how work done be a force on an object is related to the force acting on the object and the displacement of the object.
* The actual investigation should take between 50 minutes and 90 minutes.
* Be guided by the philosophy exposed in the attached ILE/ILD (Interactive Laboratory Experience/Interactive Lecture Demonstration) document with special attention to promoting individual intellectual risk taking and discourse among students.

(See Appendix I) |
| *Please provide enough information and details so the teacher can deliver the lesson.*This lesson follows Lesson #2. In Lesson #2 students learned to distinguish between the common language definition of work and the scientific definition of work. By the end of Lesson #2 the students were able to compute the work done by both constant and varying forces by using the defining formula or the concept of the area under the force-displacement graph.Lesson #3 begins with Investigation L3. You may either have students read about power before, during or after the investigation. Students through the investigation will learn the definition of power (i.e., the time-rate of change of work), how to compute power and use the new found understanding of work and power to solve a fun problem involving the exercise required to burn off the Calories contained in a Snickers bar. While doing the investigation, students will also learn to represent the measure of work and power in different conventional units (i.e., Work - Joules, calories and Calories; Power - Joules/second, Watts and Horsepower).Begin investigation L3 with a brief general statement of what the students are about to investigate (i.e., “We will use this investigation to examine the scientific definition of another important physics concept that has found its way into our common language, i.e. power. Prior to doing the investigation and prior to assigning reading on this concept, Inquire into the students thinking about this physics concept of Power. You might ask; “What does it mean to say someone is powerful?” to highlight the distinction between Power in physics and power in common usage.During the activity the teacher ‘s role is to facilitating on-task behavior, answer “clarification” questions, probe student thinking, remind students of past knowledge, and to respond to student questions, as best as possible, with guided questions (i.e., the discourse can be generally characterized as “Socratic.”). Leading questions from the teacher may stretch the student’s thinking significantly or may contain hints and only require a small leap of thinking from the student. The instructor will use their best judgment based on the needs of their individual students and the students’ ability to tolerate potential frustration during this back-and-forth questioning.Once the investigation is completed the instructor should lead a discussion to make sure the students have responded to the investigation correctly and that the students within the class all have a comfortable understanding of this new physics concept (i.e., power). All students should do Problems 3.1 and 3.2. |
| *Extended Learning/Practice (homework)* |
| Closure*Review outcomes of this lesson:* K1: The causal agent for the transfer of energy (work) is the result of force acting over a displacement (actually the component of the force in the direction of the displacement (e.g., W= **F**average •**∆d**).K2. Power is the rate at which work is performed and is proportional to the work done and inversely proportional to the time it takes to perform the work (e.g., Pavg = Work/∆t.)S2: Use the formula W = **F**average **•∆d** to analyze and compute the work done on an object by a force.S3. Use the formula Pavg = W/∆t to compute the average power for a given situation.S7. Use the strategy of computing the area under a force-displacement graph to determine the work done by a force.S9. Articulate how energy is transferred between systems.S11. Use data gathered through experiments to analyze and draw conclusions.S12. Use evidence and scientific and mathematical reasoning to communicate experimental results and to make claims.*Preview outcomes for the next lesson:*Students will extend their understanding of work to the idea of kinetic energy (i.e., energy of motion) and we introduce the “big” idea of the Work-Energy Theorem (i.e., the net work done on an object is equal to the change in kinetic energy of the object). |

Teacher Reflection (to be completed after lesson)

|  |
| --- |
| What went well in this lesson?Did all students accomplish the outcome(s))? What evidence do I have?What would I do differently next time? |

**Investigation #L3:**  Power – Snickers Laboratory Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_



**I. Experiment - Burning off the Calories in a Snicker bar.**

We will run up a flight of stairs & determine the work performed & power generated in doing this task. We will then use our understanding of how to computer work and power to determine how many times we would have to run of the flight of stairs to burn off the Calories contained in a Snickers bar

**II. Definitions**

***Work***: The work done by a force is equal to the average force exerted on an object times the distance the object moves in the direction the force is acting. (i.e., W=Faverage•∆din direction of force).

***Power***: The power generated by a force is equal to the rate at which work is performed by that force (i.e., P=W/∆t).

**III. Predictions**

1a. **Claim:** You and Mr. Greenman run up the same flight of stairs in the same amount of time. Who does more work?

1b. **Evidence:** State your reasoning for the claim you made.

1c. **Claim:** You and Mr. Greenman run up the same flight of stairs in the same amount of time. Who generates more power?

1d. **Evidence:** State your reasoning for the claim you made.

2a. **Claim:** You run up the 1st flight of stairs in a given amount of time. You run up the second flight (same height as first flight) in half the time. In which case do you do more work?

2b. **Evidence:** State your reasoning for the claim you made.

2c. **Claim:** You run up the 1st flight of stairs in a given amount of time. You run up the second flight (same height as first flight) in half the time. In which case do you generate more power?

2d. **Evidence:** State your reasoning for the claim you made.

**IV. Small Group Discussion**

Share your results with your laboratory partners and dialog about your various claims and evidential statements.

**V. Nature Speaks**

3a. Use the force plate to determine the force the floor exerts on you to raise your body one step in height.

 Step Height (m): \_\_\_\_\_\_\_\_\_\_ Force Exerted (N): \_\_\_\_\_\_\_\_\_\_\_\_

3b. Determine the number of steps required to go up one flight of stairs.

 Number of Steps: \_\_\_\_\_\_\_\_\_\_ Total Height of Flight (m): \_\_\_\_\_\_\_\_\_\_\_\_

3c. Determine the time it takes you to raise your body up this flight of stairs.

 Time (s): \_\_\_\_\_\_\_

4. Calculate the minimum work done by the force of your foot pushing against the floor raising your boy the height of one flight of stairs. Formula, substitution with units, and answer with units.

5. Calculate the power this force generated in raising your body up one flight of stairs. Formula, substitution with units, and answer with units (note 1 joule/s = 1 watt).

6. Either by setting up ratios or using the techniques of dimensional conversion, determine how much horsepower you generated (750 watts = 1.0 horsepower).

7. Either by setting up multiple ratios or using the techniques of dimensional conversion, determine how many times you would have to run up this stairwell to burn off the calories in a 280 Calorie Snicker's bar. (4.2j=1.0 calorie, and 1000 calories = 1 Calorie by definition).

**PROBLEM 3.1**

A small motor is used to raise a mass from the ground to the 2nd floor of a building under construction. The object moves from the ground to the 2nd floor platform 8.0 m above the ground at a constant speed of 2.0 m/s. The mass of the object being raised is 25.0 kg. (a) Draw a force diagram showing all the forces acting on the mass as it is raised. (b) Determine the minimum power in watts and horsepower developed by this engine while lifting the object. Clarity of communicating your solution will be an important factor in the assessment of your work (pun!).

**PROBLEM 3.2**

The same object is raised to the 3rd floor (12.0 m above the ground) from the ground at the same speed as in problem #1 above. (a) In which case (#1 or #2) is more work done by the motor? (b) In which case (#1 or #2) is more power generated by the motor? You must support your claims for (a) and (b) with clearly documented evidence and/or convincing argument based on physics principles.

Content Area/Course: **Physics** Grade(s): **9-12** Date: Time (minutes or hours): 3 class period (~2.5 hours)

Unit Title: **Energy**

Lesson Title: **Lesson 4 – Work and Kinetic Energy**

Essential Question(s) to be addressed in this lesson:

Standard(s)/Unit Goal(s) to be addressed in this lesson: G1, G2, G5, G9, G10, G12, G13

Assumptions about what students know and are able to do coming into this lesson (including language needs): Same as prescribed in Lesson #3 plus Lesson #3 outcomes.

Where this lesson comes in a sequence: Lesson #4 of 7

 Beginning Middle End

Outcome(s)

*By the end of this lesson students will know and be able to:*

K1: The causal agent for the transfer of energy (work) is the result of force acting over a displacement (actually the component of the force in the direction of the displacement (e.g., W= **F**average •**∆d**).

K2. Power is the rate at which work is performed and is proportional to the work done and inversely proportional to the time it takes to perform the work (e.g., Pavg = Work/∆t.)

K3. The relationship between energy of motion (kinetic energy), mass and speed (qualitatively and quantitatively – larger speed 🡺 greater KE and KE ~ v2; large mass 🡪 greater K and KE ~ m)

S2: Use the formula W = **F**average **•∆d** to analyze and compute the work done on an object by a force.

S3. Use the formula Pavg = W/∆t to compute the average power for a given situation.

S4. Use the formula KE=.5mv2 to compute the kinetic energy of an object.

S7. Use the strategy of computing the area under a force-displacement graph to determine the work done by a force.

S9. Articulate how energy is transferred between systems.

S11. Use data gathered through experiments to analyze and draw conclusions.

S12. Use evidence and scientific and mathematical reasoning to communicate experimental results and to make claims.

Instructional Resources/Tools (What does the complexity of these texts or sources demand of the students?)

|  |
| --- |
| **•** Investigation: Work and Kinetic Energy L4• You may either have students read about work and kinetic energy before, during or after the investigation.• Problems 4.1 and 4.2 |

Anticipated Student Preconceptions/Misconceptions

|  |
| --- |
| **Potential Mis-conceptions:**• Something not moving can't have any energy. • A force that acts on an object does work even if the object does not move. • Energy is not related to Newton's laws. • Energy is a force.• Work is energy.• Students may believe that energy is truly lost in many energy transformations. |

Assessment

|  |  |
| --- | --- |
| Pre-assessment/ Formative  | Summative (optional) |
| Investigations L4 expository and dialog, Problems 4.1 and 4.2  |  |

|  |  |
| --- | --- |
| Lesson Sequence and Description | *This column may be used to suggest/provide:** The students should have an understanding of the relationship between kinematic variables. an understanding of Newton’s 1st, 2nd, and 3rd laws and how work done be a force on an object is related to the force acting on the object and the displacement of the object.
* The actual investigation should take between 50 minutes and 90 minutes.
* Be guided by the philosophy exposed in the attached ILE/ILD (Interactive Laboratory Experience/Interactive Lecture Demonstration) document with special attention to promoting individual intellectual risk taking and discourse among students.

(See Appendix I) |
| *Please provide enough information and details so the teacher can deliver the lesson.*This lesson follows Lesson #3. In Lesson #3 students learned to distinguish between the common language usage of power and the scientific definition of power. Lesson #3 continued to reinforce the concept of Work (the measure of energy transfer). By the end of Lesson #3 the students were able to understand the relationship between power, work and time and to compute power and convert power between the units of Watts and Horsepower.Lesson #4 begin with a few demonstrations: (1) an applied horizontal force acting on an object that can move over a frictionless surface; (2) an applied vertical force (gravity) acting on an object (not subject to air resistance) that is dropped; etc. The purpose of the demonstrations would be for the students to realize (without the instructor first telling) that when a force acts over a displacement (i.e., work is being done) that the object may speed up. Following the demonstration and brief class discussion, begin Investigation L4 with a brief general statement sharing the general purpose of the investigation (i.e., “We will use this investigation to examine what might happen to an object when work is done on it – to look for a quantitative relationship between the work done and how the object’s motion might change?” During the activity the teacher ‘s role is to facilitating on-task behavior, answer “clarification” questions, probe student thinking, remind students of past knowledge, and to respond to student questions, as best as possible, with guided questions (i.e., the discourse can be generally characterized as “Socratic.”). Leading questions from the teacher may stretch the student’s thinking significantly or may contain hints and only require a small leap of thinking from the student. The instructor will use their best judgment based on the needs of their individual students and the students’ ability to tolerate potential frustration during this back-and-forth questioning.Once Investigation L4 is completed the instructor should lead a discussion to make sure the students have responded to the investigation correctly and that the students within the class all have a comfortable understanding of this new concept (i.e., kinetic energy and its relationship to work). All students should do Problems 4.1 and 4.2. |
| *Extended Learning/Practice (homework)* |
| Closure*Review outcomes of this lesson:* K1: The causal agent for the transfer of energy (work) is the result of force acting over a displacement (actually the component of the force in the direction of the displacement (e.g., W= **F**average •**∆d**).K2. Power is the rate at which work is performed and is proportional to the work done and inversely proportional to the time it takes to perform the work (e.g., Pavg = Work/∆t.)K3. The relationship between energy of motion (kinetic energy), mass and speed (qualitatively and quantitatively – larger speed 🡺 greater KE and KE ~ v2; large mass 🡪 greater K and KE ~ m)S2: Use the formula W = **F**average **•∆d** to analyze and compute the work done on an object by a force.S3. Use the formula Pavg = W/∆t to compute the average power for a given situation.S4. Use the formula KE=.5mv2 to compute the kinetic energy of an object.S7. Use the strategy of computing the area under a force-displacement graph to determine the work done by a force.S9. Articulate how energy is transferred between systems.S11. Use data gathered through experiments to analyze and draw conclusions.S12. Use evidence and scientific and mathematical reasoning to communicate experimental results and to make claims.*Preview outcomes for the next lesson:*In Lesson 5, students will extend their understanding of work to the special case of work done by conservative forces (i.e., A force field gives rise to a conservative force if the work required to change an object’s position (displace the object) within the force field is the same no matter the physical path taken to make the displacement). The work done by conservative forces gives rise to the concept of potential energy or stored energy. We will look at work done by the two conservative forces related to gravity and a Hooke’s Law spring. |

Teacher Reflection (to be completed after lesson)

|  |
| --- |
| What went well in this lesson?Did all students accomplish the outcome(s))? What evidence do I have?What would I do differently next time? |

**Investigation L4:**  Work and Kinetic Energy Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**I. Experiment –** A first look at the **"Work-Energy" Principle**

We will investigate the motion of an object when work is done on the object.

**II. Prediction (DON'T DO THE ACTUAL EXPERIMENT YET!)**

A cart loaded with a 500g mass is pulled by a constant force as shown above.

1a. What will the graphs look like? Sketch your predictions.

2a. Claim: Is the force pulling the cart doing work?

2b. Evidence: State your rationale for your claim.

**III. Small Group Discussion**

Share your predictions with your laboratory partners and dialog with them concerning the "correctness" of the predictions.

**IV. Larger Group Discussion**

Share your lab group’s prediction with another lab group. Present your findings with conviction and clarity, listen to the other lab group explanation respectfully and with an open mind and reflect on any differences in thinking.

**V. Modify Results** (if you made no change, you MUST write in large letters **NC** right on **each** graph)

3a. What will the graphs look like? Sketch your modified predictions.

3b. Claim: Is the force pulling the cart doing work?

3c. Evidence: State your rationale for your claim.

**VI. Nature Speaks (Set up the apparatus as shown)**

Either open the teacher prepared file or create a screen that contains the following two graphs. Rearrange the graphs so they appear on your screen as shown below.





Add 500g to the cart. Place a 50g mass on the slot-hook hanger. With the force probe hook unloaded, zero the force probe. Set up the system as shown above. Make sure the cart will reach the end of the track **before** the weight hits the ground. While holding the cart in place, click "collect data" and then let the cart go. Store the run.

4. Print out the graphs if your class has that capability. Sketch the graphs in the space provided above.

 **VI. Analysis – Making Sense of the Data**

5. Use the force-position graph to determine the total work done on the cart (we assume that the tension in the string recorded by the force probe is the only force acting on the cart in the direction of the displacement). Show calculations and explain in words how you went about finding this quantity. Make sure you **only compute the work done while the cart moved with constant acceleration** and remember W **= Favg • ∆d and not Favg • d**

**Dimensional Consideration Guiding Our Thinking:**

6a. What are the fundamental units for work? Write them below.

6b. What is the name of the variable that is represented by the first fundamental unit in the expression you wrote in 6a?

6c. What is the name of the variable that represented by the ratio of units that is squared in the expression you wrote in 6a?

6d. Rewrite your unit expression in 6a, replacing the unit names with the variable names suggested by 6b and 6c.

One-half of the quantity defined by the expression in 6d has a special relationship to the physics definition for work. It is only because this quantity has a special relationship to work that we take the time to name this quantity. We name this quantity (**.**5 mv2) ***kinetic energy.*** We conceptualize this quantity as the energy associated with the motion of an object.

7. Determine the kinetic energy of the cart at the initial location associated with your work calculation in 5 above. Hint: Use your velocity-position graph to help you determine the velocity corresponding to the initial position used for your work calculation. Show your work below starting with the kinetic energy formula.

8. Determine the final kinetic energy of the cart at the final location associated with your work calculation in 5 above. Hint: Use your velocity-position graph to help you determine the velocity corresponding to the final position used for your work calculation. Show your work below starting with the kinetic energy formula.

9a. **Claim:** What is this special relationship between **change** in kinetic energy and work?

9b. **Evidence:** What evidence supports your claim.

The ***Work-Energy Principle*** states that the net work done by all forces acting on a rigid object will be equal to the change in kinetic energy of the object.

**PROBLEM 4.1**

1. You are given a force-displacement graph corresponding to the physical experiment shown next to the graph. The cart with probe has a mass of **.70**kg.



1a. Determine the quantity of work done by the tension acting on the cart. Show explicitly how you made this determination.

1b. Claim: Was the work done by the tension on the cart positive or negative?

1c. Evidence: State your rationale for your claim.

1d. How does the work done by the tension force show itself in the cart?

1e. Using the work-energy principle, predict the velocity of the cart after the cart has been displaced a total distance of .80m. Show explicitly how you determined this value.

 **PROBLEM 4.2**

1. A cart is used to push on the spring compressing the spring 60.0 cm from its rest position. The cart is held up against the spring temporarily keeping the spring compressed. Then the cart is let go and the spring is allowed to decompress. The graph below shows the **force acting on the cart** by the spring as the spring decompresses. Note that the origin is taken to be the location of the bar the spring is secured to. The cart with probe has a mass of **.70**kg.



1a. Determine the quantity of **work done by the spring force** on the cart as the spring decompresses a full 60.cm. Show explicitly how you made this determination.

1b. **Claim:** Was the **work done by the spring** on the cart positive or negative?

1c. **Evidence:** State your rationale for your claim

1d. How does the work done by the spring force show itself in the cart?

1e. Using the work-energy principle, predict the velocity of the cart after the cart has been displaced a total distance of .60m. Show explicitly how you determined this value.

Content Area/Course: **Physics** Grade(s): **9-12** Date: Time (minutes or hours): 3 class period (~2.5 hours)

Unit Title: **Energy**

Lesson Title: **Lesson 5 – Work and Potential Energy**

Essential Question(s) to be addressed in this lesson:

Standard(s)/Unit Goal(s) to be addressed in this lesson: G1, G2, G5, G7, G9, G10, G12, G13

Assumptions about what students know and are able to do coming into this lesson (including language needs): Same as prescribed in Lesson #4 plus Lesson #4 outcomes.

Where this lesson comes in a sequence: Lesson #5 of 7

 Beginning Middle End

Outcome(s)

*By the end of this lesson students will know and be able to:*

K1: The causal agent for the transfer of energy (work) is the result of force acting over a displacement (actually the component of the force in the direction of the displacement (e.g., W= **F**average •**∆d**).

K2. Power is the rate at which work is performed and is proportional to the work done and inversely proportional to the time it takes to perform the work (e.g., Pavg = Work/∆t.)

K4. Potential energy can be classified based on the type of force field in which an object is placed (e.g. electro-magnetic potential energy (chemical potential energy and elastic potential energy are specific examples of electro-magnetic potential energy),

K7. The change in potential energy of an object can be determined directly from the work done by the force field when an object is displaced in the field (e.g., ∆PE = **- F**field,avg • **∆s**).

K8. The change in gravitational potential energy for an object displaced in the near Earth gravitational field (∆PE=mg∆h) and the change in elastic (electromagnetic) potential energy due to a compressed/stretched spring (∆PE=.5ks22-.5ks12) follows directly from the principle that ∆PE = **- F**field,avg • **∆s**.

K9. A force field gives rise to a conservative force if the work to change the object’s position (displace the object) within the force field is the same no matter the physical path taken to make the displacement.

S2: Use the formula W = Faverage •∆d to analyze and compute the work done on an object by a force.

S3. Use the formula Pavg = W/∆t to compute the average power for a given situation.

S5. Use the formula PE=mgh to compute the potential energy of the Earth-object system when an object is located near the Earth’s surface (where h is the distance from an arbitrary reference point often chosen to be the Earth’s surface or the closes point to the Earth’s surface an object gets for a specific problem).

S6. Use the formula PE=.5ks2 to compute the potential energy of a Hooke’s law spring.

S7. Use the strategy of computing the area under a force-displacement graph to determine the work done by a force.

S9. Articulate how energy is transferred between systems.

S11. Use data gathered through experiments to analyze and draw conclusions.

S12. Use evidence and scientific and mathematical reasoning to communicate experimental results and to make claims.

Instructional Resources/Tools (What does the complexity of these texts or sources demand of the students?)

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| **•** Investigation: Work and Potential Energy L5• FOLLOWING the Investigation readings should be assigned from any introductory physics text dealing with the concept of potential energy• Problems 5.1 – 5.4 |

Anticipated Student Preconceptions/Misconceptions

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| **Potential Mis-conceptions:**• Something not moving can't have any energy. • A force that acts on an object does work even if the object does not move. • Energy is not related to Newton's laws. • Energy is a force.• Work is energy.• Students may believe that energy is truly lost in many energy transformations. |

Assessment

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| Pre-assessment/ Formative  | Summative (optional) |
| Investigation L5, expository and dialog, Problems 5.1 – 5.4, L5.4 |  |

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| Lesson Sequence and Description | *This column may be used to suggest/provide:** The students should have an understanding of the relationship between kinematic variables. an understanding of Newton’s 1st, 2nd, and 3rd laws and how work done be a force on an object is related to the force acting on the object and the displacement of the object.
* The actual investigation should take between 50 minutes and 90 minutes.
* Be guided by the philosophy exposed in the attached ILE/ILD (Interactive Laboratory Experience/Interactive Lecture Demonstration) document with special attention to promoting individual intellectual risk taking and discourse among students.

(See Appendix I) |
| *Please provide enough information and details so the teacher can deliver the lesson.*This lesson follows Lesson #4. In Lesson #4 students learned about the concept of kinetic energy (i.e., energy of motion) and were introduce to the Work-Energy Theorem (i.e., the net work done on an object is equal to the change in kinetic energy of the object).Lesson #5 begin with a few demonstrations: (1) an object acted on by a force (not subject to air resistance) is raised a height without changing the objects speed; (2) a spring is acted on by a force without a change in the spring’s speed, etc. The purpose of the demonstrations would be for the students to realize (without the instructor first telling) that when a force acts (NOT the net force) over a displacement (i.e., work is being done) that the object does not always change its speed. This is to pose the dilemma of: “Where did the energy transfer to?” and leads to the idea of potential energy (energy of position within a conservative field).Following the demonstration and brief class discussion, begin the Investigation L5 with a brief general statement sharing the general purpose of the Investigation (i.e., “We will use this investigation to examine what happens to the transferred energy when an object is displace within a gravitational field or when a spring is stretched/compressed (changes are made in the electro-magnetic field within the spring)?” During the activity the teacher ‘s role is to facilitating on-task behavior, answer “clarification” questions, probe student thinking, remind students of past knowledge, and to respond to student questions, as best as possible, with guided questions (i.e., the discourse can be generally characterized as “Socratic.”). Leading questions from the teacher may stretch the student’s thinking significantly or may contain hints and only require a small leap of thinking from the student. The instructor will use their best judgment based on the needs of their individual students and the students’ ability to tolerate potential frustration during this back-and-forth questioning.Once the Investigation is completed the instructor should lead a discussion to make sure the students have responded to the Investigation correctly and that the students within the class all have a comfortable understanding of these new concepts (i.e., potential energy, conservative forces and non-conservative forces and the relationship between potential energy and conservative forces). All students should do Problems 5.1 – 5.4. |
| *Extended Learning/Practice (homework)* |
| Closure*Review outcomes of this lesson:* K1: The causal agent for the transfer of energy (work) is the result of force acting over a displacement (actually the component of the force in the direction of the displacement (e.g., W= **F**average •**∆d**).K2. Power is the rate at which work is performed and is proportional to the work done and inversely proportional to the time it takes to perform the work (e.g., Pavg = Work/∆t.)K4. Potential energy can be classified based on the type of force field in which an object is placed (e.g. electro-magnetic potential energy (chemical potential energy and elastic potential energy are specific examples of electro-magnetic potential energy),K7. The change in potential energy of an object can be determined directly from the work done by the force field when an object is displaced in the field (e.g., ∆PE = **- F**field,avg • **∆s**).K8. The change in gravitational potential energy for an object displaced in the near Earth gravitational field (∆PE=mg∆h) and the change in elastic (electromagnetic) potential energy due to a compressed/stretched spring (∆PE=.5ks22-.5ks12) follows directly from the principle that ∆PE = **- F**field,avg • **∆s**.K9. A force field gives rise to a conservative force if the work to change the object’s position (displace the object) within the force field is the same no matter the physical path taken to make the displacement.S2: Use the formula W = Faverage •∆d to analyze and compute the work done on an object by a force.S3. Use the formula Pavg = W/∆t to compute the average power for a given situation. S5. Use the formula PE=mgh to compute the potential energy of the Earth-object system when an object is located near the Earth’s surface (where h is the distance from an arbitrary reference point often chosen to be the Earth’s surface or the closes point to the Earth’s surface an object gets for a specific problem).S6. Use the formula PE=.5ks2 to compute the potential energy of a Hooke’s law spring.S7. Use the strategy of computing the area under a force-displacement graph to determine the work done by a force.S9. Articulate how energy is transferred between systems.S11. Use data gathered through experiments to analyze and draw conclusions.S12. Use evidence and scientific and mathematical reasoning to communicate experimental results and to make claims.*Preview outcomes for the next lesson:*Students will extend their understanding of work, kinetic energy, potential energy and the Work-Energy Theorem to the idea of Conservation of Energy and Conservation of Mechanical Energy under special circumstances (i.e., only conservative forces acting on the system).  |

Teacher Reflection (to be completed after lesson)

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| What went well in this lesson?Did all students accomplish the outcome(s))? What evidence do I have?What would I do differently next time? |

**Investigation L5:**  Revision of the Work-Energy Principle Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. **Activity**

To examine further what happens when ***work*** is performed on an object

1. **Past Knowledge Brought Forward**

Restate the scientific definition and conceptual meaning for Work: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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Restate the definition and conceptual meaning for Kinetic Energy: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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Restate the Work Energy principle: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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1. **Extending the Work-Energy Principle to a System of Objects**

Work-Energy Principle: W net = **F** net • **∆d** = ∆KE object

Instead of only considering work done on a single rigid object ***we will now consider the case of work done on a system of objects.*** When we consider work done on a system of objects it is useful to separate the net work done on the system into the work done by forces external to the system and work done by forces internal to the system. It is further useful to separate the net work done by internal forces into work done by “conservative” forces and work done by “non-conservative” forces. After making these two adjustments, by convention we isolate the work done by the external forces on one side of our rewritten Work-Energy relationship:

**F**net, external • **∆d** + **F**net, internal • **∆d** = ∆KE system (1)

**F**net, external • **∆d** + **F**net, internal conservative force • **∆d** + **F**net, internal non-conservative force • **∆d** = ∆KE system (2)

**F**net, external • **∆d** = ∆KE system + (- **F**net, internal conservative force • **∆d)** + (-**F**net, internal non-conservative force • **∆d)** (3)

**Conservative Forces and Potential Energy**

 An interactive force is considered to be a ***conservative force*** if the work done by the force of interaction is ***independent of the physical path taken*** or equivalently an interactive force is considered a conservative force if the work done by the force of interaction ***is zero when the object moves over any closed path***. When dealing with conservative forces, we define a new concept called the ***change in*** ***potential*** *energy*. The change in potential energy (∆U) is defined as the negative of the work done by the conservative force over a displacement.

∆U = - **F**net, internal conservative force • **∆d**

The gravitations force and elastic force involved in Hooke’s law springs are examples of conservative forces.

***Individual Conjecture:*** Take a moment to develop an argument to convince your laboratory partners that the gravitational force is a conservative force. Place a summary of your argument below:

***Small Group Discussion***: Share your thinking with your laboratory partners.

***Large Group Discussion and modifications***: Share your thinking with the laboratory group nearest to you. If needed re-write a modified argument below.

**F**net, external • **∆d** = ∆KEsystem + ∆U + (-**F**net, internal non-conservative force • **∆d) (4)**

The last term in our revised Work-Energy Principle, equation (4) above, is the change in internal energy of the system resulting from all internal non-conservative forces acting within the system. With this awareness, we can rewrite this term as:

∆E internal = -**F**net, internal non-conservative force • **∆d**

The revised form for our Work-Energy Principle follows:

**W** net, external= ∆KE system + ∆U + ∆E internal **(5)**

**This is a really BIG idea in physics!**

†The only additional modification to this idea will arise during a study of thermodynamics where a second term will be added to the left hand side: Q, denoting the energy transferred to or away from the system by heat.

1a. A 2.5 kg book is raised .50m off of your desk. Draw a force diagram illustrating and naming all the forces acting on the book.

1b. Determine the work done by the conservative gravitational force as you raise the book. Is the work done by the gravitational force positive or negative - explain?

1c. Determine the change in gravitational potential energy of the book-earth system when the book is raised .50m off of your desk. Is the change in gravitational potential energy positive or negative – explain?

2a. A 35 kg child slides down the incline shown below. Draw a force diagram illustrating all the forces acting on the child.

5m

3m

4m

2b. Determine the work done by the gravitational force as a 35kg child slides down the incline plane. Is the work done by the gravitational force positive or negative –explain?

2c. Determine the change in gravitational potential energy of the child-earth system when the child slides down the incline plane. Is the change in gravitational potential energy positive or negative – explain.

2d. Using the revised **work-energy principle,** determine the speed of the child as she gets to the bottom of the ramp. Assume no frictional forces.

3a. A 2.0kg ball initially 1.0m above the ground and held in your hand is pushed upward by you with a 220.N force over a vertical distance of .50m and then allowed to fly upward from your hand. Using the revised ***work-energy principle****,* determine the maximum height the ball rises above the ground.

3b. Using the work-energy principle, determine the speed the ball would have just prior to striking the ground.

4. Determine the ***potential energy*** stored in a Hooke's Law spring with a spring constant 250N/m when the spring is compressed a distance of 25 cm from the spring's natural length.

5a. A block of mass=4.0kg sliding with an initial speed of 5.0m/s across a frictionless tabletop collides with a spring having a spring constant of 250N/m. The natural length of the spring is .80m. Draw a force diagram illustrating and naming all the forces acting on the block as it collides with the spring.

5b. Using the work-energy principle, determine the maximum compression of the spring from its natural length as the block collides with this spring.

**PROBLEM 5.1**

A 4.0 kg ball is dropped from a height of 3.05 meters above a hard wood floor. You place a soft pad 5.0 cm thick on the wood floor and then drop the ball. (a) Draw a force diagram on the ball as it is falling freely toward the ground. (b) Using the Work-Energy Principle, determine the speed of the object just as it is to crash into the pad on the floor. Clearly document your work including appropriate use of units.

**PROBLEM 5.2**

(a) Draw a force diagram showing all the forces acting on the ball as it is being stopped by the pad. The ball crushes the pad to a thickness of 2.0 cm while being stopped by the pad. (b) Using the Work-Energy Principle, determine the average net force acting on the ball while being stopped by the pad. (c) Determine the average force of the pad acting on the ball while being stopped. Clearly document your work including appropriate use of units.

**PROBLEM 5.3**

A 4.0 kg sled is pulled with a horizontal force of 16 N and is seen to move with a constant speed of 2.0 m/s. The force is suddenly increased to 24 N. Draw a force diagram showing all forces acting on the sled as it is pulled by the 24 N force. Using the Work-Energy Principle, determine the speed of the sled after moving 3.0 m from the time the 24n force started to act.

**PROBLEM 5.4**

A Hooke’s law spring is compressed 22 cm. The spring is on a horizontal table and has a spring constant of 650 N/m. A 320 g mass is placed against the compressed spring. The frictional force that acts on the object while sliding is 1.0 N and the distance along the table between the object while compressed and the edge of the table is 4.0 m. The top of the table is 2.0 m off the floor. (a) Draw a force diagram showing all forces acting on the mass while the spring is pushing the mass. (b) Draw a force diagram showing all forces acting on the mass free of the spring but still sliding on the table top. (c) Using the Work-Energy Principle, determine the speed of the object just as it flies off the edge of the table. Document your work clearly and use units appropriately.

Content Area/Course: **Physics** Grade(s): **9-12** Date: Time (minutes or hours): 6 class period (~5.0 hours)

Unit Title: **Energy**

Lesson Title: **Lesson 6 – Conservation of Energy**

Essential Question(s) to be addressed in this lesson:

Standard(s)/Unit Goal(s) to be addressed in this lesson: G1, G2, G3, G4, G5, G6, G7, G9, G10, G12, G13, G14, G15

Assumptions about what students know and are able to do coming into this lesson (including language needs): Same as prescribed in Lesson #5 plus Lesson #5 outcomes.

Where this lesson comes in a sequence: Lesson #6 of 7

 Beginning Middle End

Outcome(s)

*By the end of this lesson students will know and be able to:*

K1: The causal agent for the transfer of energy (work) is the result of force acting over a displacement (actually the component of the force in the direction of the displacement (e.g., W= **F**average •**∆d**).

K2. Power is the rate at which work is performed and is proportional to the work done and inversely proportional to the time it takes to perform the work (e.g., Pavg = Work/∆t.)

K3. The relationship between energy of motion (kinetic energy), mass and speed (qualitatively and quantitatively – larger speed 🡺 greater KE and KE ~ v2; large mass 🡪 greater K and KE ~ m)

K4. Potential energy can be classified based on the type of force field in which an object is placed (e.g. electro-magnetic potential energy (chemical potential energy and elastic potential energy are specific examples of electro-magnetic potential energy),

K5. Energy can be transferred and transformed between and within potential energy and kinetic energy.

K6. Conservation of energy means the total change of energy in any system is equal to the sum of the energy transferred into the system plus out of the system.

K7. The change in potential energy of an object can be determined directly from the work done by the force field when an object is displaced in the field (e.g., ∆PE = **- F**field,avg • **∆s**).

K8. The change in gravitational potential energy for an object displaced in the near Earth gravitational field (∆PE=mg∆h) and the change in elastic (electromagnetic) potential energy due to a compressed/stretched spring (∆PE=.5ks22-.5ks12) follows directly from the principle that ∆PE = **- F**field,avg • **∆s**.

K9. A force field gives rise to a conservative force if the work to change the object’s position (displace the object) within the force field is the same no matter the physical path taken to make the displacement.

K10. When only conservative forces act on a system, ∆KE = -∆PE or Total Mechanic Energy remains constant over time.

S2: Use the formula W = Faverage •∆d to analyze and compute the work done on an object by a force.

S4. Use the formula KE=.5mv2 to compute the kinetic energy of an object.

S5. Use the formula PE=mgh to compute the potential energy of the Earth-object system when an object is located near the Earth’s surface (where h is the distance from an arbitrary reference point often chosen to be the Earth’s surface or the closes point to the Earth’s surface an object gets for a specific problem).

S6. Use the formula PE=.5ks2 to compute the potential energy of a Hooke’s law spring.

S7. Use the strategy of computing the area under a force-displacement graph to determine the work done by a force.

S8. Use the formula Wexternal + Wnon-conservative = ∆KE + ∆PE to analyze and solve problems of energy transfer.

S9. Articulate how energy is transferred between systems.

S10. Use the concept of conservation of energy to predict and describe system (position and speed) behavior.

S11. Use data gathered through experiments to analyze and draw conclusions.

S12. Use evidence and scientific and mathematical reasoning to communicate experimental results and to make claims.

Instructional Resources/Tools (What does the complexity of these texts or sources demand of the students?)

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| **•** Investigation: Total Energy L6• You may either have students read about total energy before, during or after the investigation.• Problems 6.1 – 6.5 (required); 6.6 (optional). |

Anticipated Student Preconceptions/Misconceptions

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| --- |
| **Potential Mis-conceptions:**• Something not moving can't have any energy. • A force that acts on an object does work even if the object does not move. • Energy is not related to Newton's laws. • Energy is a force.• Work is energy.• Students may believe that energy is truly lost in many energy transformations. |

Assessment

|  |  |
| --- | --- |
| Pre-assessment/ Formative  | Summative (optional) |
| Investigation L6, expository and dialog, Problems 6.1 – 6.5 (required); 6.6 (optional). |  |

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| --- | --- |
| Lesson Sequence and Description | *This column may be used to suggest/provide:** The students should have an understanding of the relationship between kinematic variables. an understanding of Newton’s 1st, 2nd, and 3rd laws and how work done be a force on an object is related to the force acting on the object and the displacement of the object.
* The actual investigation should take between 50 minutes and 90 minutes.
* Be guided by the philosophy exposed in the attached ILE/ILD (Interactive Laboratory Experience/Interactive Lecture Demonstration) document with special attention to promoting individual intellectual risk taking and discourse among students.

(See Appendix I) |
| *Please provide enough information and details so the teacher can deliver the lesson.*This lesson follows Lesson #5. In Lesson #5 students learned about the concept of potential energy (i.e., energy of position) and were introduced to the idea of conservative forces (i.e., a force field gives rise to a conservative force if the work to change the object’s position (displace the object) within the force field is the same no matter the physical path taken to make the displacement) and non-conservative forces.Lesson #6 begin with a few demonstrations: (1) a “Newton’s Cradle” apparatus (multiple pendulum all lined up); (2) an object thrown straight into the air or dropped from a fixed height; (3) a compressed spring either stopping a moving object or setting into motion an originally stationary object, etc. The purpose of the demonstrations would be for the students to realize (without the instructor first telling) that energy can transform between and within potential energy, kinetic energy and non-conserved forms of energy.Following the demonstration and brief class discussion, begin Investigation L6 with a brief general statement sharing the general purpose of the Investigation (i.e., “We will use this investigation to examine the relationship between potential energy and kinetic energy as energy is transferred between them. During the activity the teacher ‘s role is to facilitating on-task behavior, answer “clarification” questions, probe student thinking, remind students of past knowledge, and to respond to student questions, as best as possible, with guided questions (i.e., the discourse can be generally characterized as “Socratic.”). Leading questions from the teacher may stretch the student’s thinking significantly or may contain hints and only require a small leap of thinking from the student. The instructor will use their best judgment based on the needs of their individual students and the students’ ability to tolerate potential frustration during this back-and-forth questioning.Once the investigation is completed the instructor should lead a discussion to make sure the students have responded to the investigation correctly and that the students within the class all have a comfortable understanding of these new and related concepts (i.e., conservation of energy and conservation of total mechanical energy).In the follow up activities and discussion of the results of the Investigation look at situations where energy may transfer to internal energy and/or be lost to our defined system through non-conservative forces and/or external forces acting. All students should do Problems 6.1 - 6.5.The draft concept map developed in Lesson #1 should be revisited and modified to reflect new knowledge. |
| *Extended Learning/Practice (homework)*Problem 6.6 is an optional extension (please look at it to determine if they would be appropriate for your students). |
| Closure*Review outcomes of this lesson:* K1: The causal agent for the transfer of energy (work) is the result of force acting over a displacement (actually the component of the force in the direction of the displacement (e.g., W= **F**average •**∆d**).K2. Power is the rate at which work is performed and is proportional to the work done and inversely proportional to the time it takes to perform the work (e.g., Pavg = Work/∆t.)K3. The relationship between energy of motion (kinetic energy), mass and speed (qualitatively and quantitatively – larger speed 🡺 greater KE and KE ~ v2; large mass 🡪 greater K and KE ~ m)K4. Potential energy can be classified based on the type of force field in which an object is placed (e.g. electro-magnetic potential energy (chemical potential energy and elastic potential energy are specific examples of electro-magnetic potential energy),K5. Energy can be transferred and transformed between and within potential energy and kinetic energy.K6. Conservation of energy means the total change of energy in any system is equal to the sum of the energy transferred into the system plus out of the system.K7. The change in potential energy of an object can be determined directly from the work done by the force field when an object is displaced in the field (e.g., ∆PE = **- F**field,avg • **∆s**).K8. The change in gravitational potential energy for an object displaced in the near Earth gravitational field (∆PE=mg∆h) and the change in elastic (electromagnetic) potential energy due to a compressed/stretched spring (∆PE=.5ks22-.5ks12) follows directly from the principle that ∆PE = **- F**field,avg • **∆s**.K9. A force field gives rise to a conservative force if the work to change the object’s position (displace the object) within the force field is the same no matter the physical path taken to make the displacement.K10. When only conservative forces act on a system, ∆KE = -∆PE or Total Mechanic Energy remains constant over time.S2: Use the formula W = Faverage •∆d to analyze and compute the work done on an object by a force.S4. Use the formula KE=.5mv2 to compute the kinetic energy of an object.S5. Use the formula PE=mgh to compute the potential energy of the Earth-object system when an object is located near the Earth’s surface (where h is the distance from an arbitrary reference point often chosen to be the Earth’s surface or the closes point to the Earth’s surface an object gets for a specific problem).S6. Use the formula PE=.5ks2 to compute the potential energy of a Hooke’s law spring.S7. Use the strategy of computing the area under a force-displacement graph to determine the work done by a force.S8. Use the formula Wexternal + Wnon-conservative = ∆KE + ∆PE to analyze and solve problems of energy transfer.S9. Articulate how energy is transferred between systems.S10. Use the concept of conservation of energy to predict and describe system (position and speed) behavior.S11. Use data gathered through experiments to analyze and draw conclusions.S12. Use evidence and scientific and mathematical reasoning to communicate experimental results and to make claims.*Preview outcomes for the next lesson:*Students will apply all they have learned about work (energy transfer), kinetic energy, potential energy, conservation of total energy, conservation of total mechanical energy and Newton’s laws to solve a problem of building a Mousetrap car under specified constraints. |

Teacher Reflection (to be completed after lesson)

|  |
| --- |
| What went well in this lesson?Did all students accomplish the outcome(s))? What evidence do I have?What would I do differently next time? |

**Investigation L6: Total Mechanical Energy**

I.  **Experiment**

We will analyze the changes in energy as an object falls.

II. **Individual Predictions**

 You displace a 500g mass a vertical distance of 2.0m by applying a constant force that raises the mass slowly and with a constant speed to its new stationary vertical position above the floor.

1a. What kind of energy relative to the ground does the mass have while it is held stationary at its raised position?

1b. Determine the value of each kind of energy you named in 1a. Show explicitly any calculations you make to determine the energy value(s). **Quantitative** result required.

2a. The 500g mass falls .50m from its 2.0m height. What kind of energy or energies does the mass have while it passes through the location that is 1.5m above the floor?

2b. How has the amount of potential energy of the mass changed? How has the kinetic energy of the mass changed? **Qualitative** answers only.

3a. The mass falls 1.0m from its 2.0m height? What kind of energy or energies does the mass have while it passes through the location that is 1.0m above the sonic detector?

3b. How has the amount of potential energy of the mass changed from 2a? How has the kinetic energy of the mass changed from 2a? **Qualitative** answers only.

4a. The mass falls 2.0m from its 2.0m height? What kind of energy or energies does the mass have just as it is about to crash into the floor (the original location of the mass)?

4b. How has the amount of potential energy of the mass changed from 3a? How has the kinetic energy of the mass changed from 3a? **Quantitative** answers required! Give clear explanation of how you arrived at your answers and show explicitly any calculations performed in arriving at your answers.

***Small Group Discussion***: Share your thinking with your laboratory partners.

***Large Group Discussion and modifications***: Share your thinking with the laboratory group nearest to you. If needed number and re-write your altered responses in the space below.

III. **Nature Speaks**

 Drop a mass from approximately 2 meters off the ground.

5. Obtain data from either a tickertape timer drop or a sonic detector drop. Fill in the missing cells in the table below. You must show an explicit calculation showing formula used, substitution with units and answer with units for the cells marked with a †. Show your work in the space below the table.

Maximum Height: \_\_\_\_\_\_\_\_\_\_\_\_ Mass: \_\_\_\_\_\_\_\_\_\_\_

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Height (m) | Velocity (m/s) | Potential Energy (j) | Kinetic Energy (j) | Sum of PE and KE (j) | % Diff. with Avg. |
| Max height: | 0 |  |  |  |  |
| 1.7 |  |  |  |  |  |
| 1.3 |  | † | † | † | † |
| .90 |  |  |  |  |  |
| 0 |  |  |  |  |  |
| Averages  |  |  |

6. Make a claim concerning the behavior of the sum of the PE and KE of the object as it falls. Provide evidence to support your claim.

***Total Mechanical Energy***: We define the sum of the potential energy and kinetic energy of a system as the ***total mechanical energy*** of the system. Under certain circumstances the ***total mechanical energy*** of a system behaves in a special way as seen above (i.e., the ***total mechanical energy*** of the system remains unchanged as the system changes its spatial configuration).

7a. Use the predictive power of the concept of conservation of total mechanical energy to determine the potential energy, kinetic energy, and speed of the falling mass when it is 1.5m above the ground. Show explicitly your thinking and any calculations that you make.

7b. Compare your predicted velocity to the experimental velocity. Record the two velocities below and compute the % difference between them.

IV. **Reflections: Conservation of Total Mechanical Energy is A Special Case of the General Work-Energy Principle.**

The general work-energy principle can be expressed as:

W net, external = ∆KE system + ∆U + ∆E internal

For the special case where there are **no external forces** acting and **only internal conservative forces acting**, then the general work energy principle as state below will simplify to:

0 = (KE final - KE initial) + (U final – U initial) + 0

Moving all the initial terms to one side and the final terms to the other, we have:

 KE initial + U initial = KE final + U final

Hence we see that the General Work-Energy Principle can be rewritten for the special case of **no external force**s and **only internal conservative forces** acting most succinctly as:

TME initial = TME final

**PROBLEM 6.1**

An object having a mass of 2.0kg is first observed as it moves downward at 2.0m/s. The object collides with a spring with a spring constant of 700. N/m and compresses the spring 20.cm before the object is brought to rest. Using the **Work-Energy Principle**, determine the height above the spring the object is when first spotted.

**PROBLEM 6.2**

An object having a mass of 2.0kg is first observed as it moves downward at 2.0m/s. The object collides with a spring with a spring constant of 700. N/m and compresses the spring 20.cm before the object is brought to rest. Using the **Conservation of Total Mechanical Energy**, determine the height above the spring the object is when first spotted

**PROBLEM 6.3**

A spring with a spring constant of 420 N/m is compressed a distance of 35 cm from its rest position. A metal box, mass of 250 g, is positioned so that it will be fired horizontally when the spring is released. Using the principle of **Conservation of Total Mechanical Energy** determine the velocity of the ball at location A and the height above the initial location at B. Assume a frictionless track.



**PROBLEM 6.4**

The box has a mass of 2.0 kg. The track has a radius of **.**50 m, and the box is initially placed on the track a height of 3.5R above the ground. Using the principle of **Conservation of Total Mechanical Energy**, determine the speed of the box as it passes point C



**PROBLEM 6.5**

All three blocks have the same mass. Each block starts from rest and slides without friction to the bottom of the illustrated ramp. Compare and contrast the initial potential energy, final potential energy, initial kinetic energy, final kinetic energy, initial total mechanical energy, final total mechanical energy, final speed, time duration of the motion and average speed between the cases shown.

|  |  |
| --- | --- |
| The 2 blocks have the same mass. Each block starts from rest and slides without friction to the bottom of the illustrated ramp. Compare and contrast the initial potential energy, final potential energy, initial kinetic energy, final kinetic energy, initial total mechanical energy, final total mechanical energy, final speed, time duration of the motion and average speed between the cases shown. | The second object has twice the mass of the first. Each block starts from rest and slides without friction to the bottom of the ramp. Compare and contrast the initial potential energy, final potential energy, initial kinetic energy, final kinetic energy, initial total mechanical energy, final total mechanical energy, final speed, time duration of the motion and average speed between the cases shown. |



**PROBLEM 6.6** (Optional)

The two blocks have the same mass of 3.0kg. Each block starts from rest and slides without friction to the bottom of the illustrated ramp. The first ramp makes an angle of 60. degrees w.r.t. the horizontal. The second ramp makes an angle of 30. degrees w.r.t. the horizontal. Determine the initial potential energy, final potential energy, initial kinetic energy, final kinetic energy, initial total mechanical energy, final total mechanical energy, final speed, average speed and time of descent for each of the objects.

Ramp 1 from above is extended as shown below. The block starts from rest and slides without friction to the bottom of the illustrated ramp. Determine the initial potential energy, final potential energy, initial kinetic energy, final kinetic energy, initial total mechanical energy, final total mechanical energy, final speed, average speed and time of descent for each of the objects.

Content Area/Course: **Physics** Grade(s): **9-12** Date:: Time (minutes or hours): 6 class period (~5.0 hours)

 Includes 1 class period for post-test

Unit Title: **Energy**

Lesson Title: **Lesson 7 – Mouse Trap Car**

Essential Question(s) to be addressed in this lesson:

Standard(s)/Unit Goal(s) to be addressed in this lesson: G1, G2, G3, G4, G5, G6, G8, G9, G10, G11, G12, G13, G14, G15

Assumptions about what students know and are able to do coming into this lesson (including language needs): Same as prescribed in Lesson #6 plus Lesson #6 outcomes.

Where this lesson comes in a sequence: Lesson #7 of 7

 Beginning Middle End

Outcome(s)

*By the end of this lesson students will know and be able to:*

K1: The causal agent for the transfer of energy (work) is the result of force acting over a displacement (actually the component of the force in the direction of the displacement (e.g., W= **F**average •**∆d**).

K3. The relationship between energy of motion (kinetic energy), mass and speed (qualitatively and quantitatively – larger speed 🡺 greater KE and KE ~ v2; large mass 🡪 greater K and KE ~ m)

K4. Potential energy can be classified based on the type of force field in which an object is placed (e.g. electro-magnetic potential energy (chemical potential energy and elastic potential energy are specific examples of electro-magnetic potential energy),

K5. Energy can be transferred and transformed between and within potential energy and kinetic energy.

K6. Conservation of energy means the total change of energy in any system is equal to the sum of the energy transferred into the system plus out of the system.

K7. The change in potential energy of an object can be determined directly from the work done by the force field when an object is displaced in the field (e.g., ∆PE = **- F**field,avg • **∆s**).

K8. The change in gravitational potential energy for an object displaced in the near Earth gravitational field (∆PE=mg∆h) and the change in elastic (electromagnetic) potential energy due to a compressed/stretched spring (∆PE=.5ks22-.5ks12) follows directly from the principle that ∆PE = **- F**field,avg • **∆s**.

K9. A force field gives rise to a conservative force if the work to change the object’s position (displace the object) within the force field is the same no matter the physical path taken to make the displacement.

K10. When only conservative forces act on a system, ∆KE = -∆PE or Total Mechanic Energy remains constant over time.

S1: Choose appropriate technology to study energy.

S2: Use the formula W = Faverage •∆d to analyze and compute the work done on an object by a force.

S4. Use the formula KE=.5mv2 to compute the kinetic energy of an object.

S5. Use the formula PE=mgh to compute the potential energy of the Earth-object system when an object is located near the Earth’s surface (where h is the distance from an arbitrary reference point often chosen to be the Earth’s surface or the closes point to the Earth’s surface an object gets for a specific problem).

S6. Use the formula PE=.5ks2 to compute the potential energy of a Hooke’s law spring.

S7. Use the strategy of computing the area under a force-displacement graph to determine the work done by a force.

S8. Use the formula Wexternal + Wnon-conservative = ∆KE + ∆PE to analyze and solve problems of energy transfer.

S9. Articulate how energy is transferred between systems.

S10. Use the concept of conservation of energy to predict and describe system (position and speed) behavior.

S11. Use data gathered through experiments to analyze and draw conclusions.

S12. Use evidence and scientific and mathematical reasoning to communicate experimental results and to make claims.

Instructional Resources/Tools (What does the complexity of these texts or sources demand of the students?)

|  |
| --- |
| **•** Investigation L7.1: Mousetrap Car Engineering Design Project• Energy Concept Inventory Post - Test |

Anticipated Student Preconceptions/Misconceptions

|  |
| --- |
| **Potential Mis-conceptions:**• Something not moving can't have any energy. • A force that acts on an object does work even if the object does not move. • Energy is not related to Newton's laws. • Energy is a force.• Work is energy.• Students may believe that energy is truly lost in many energy transformations. |

Assessment

|  |  |
| --- | --- |
| Formative  | Summative (optional) |
| Curriculum Embedded Performance Assessment (CEPA) “Mousetrap Car” is evaluated and the general principals addressed in the activity are reviewed following assessment of the CEPA. | Post test is administered following this activity**.** |

|  |  |
| --- | --- |
| Lesson Sequence and Description | *This column may be used to suggest/provide:** This is the culminating activity for this unit on work and energy.
* The actual project should take between 2 and 3 hours (~3 class periods). Some work should be done outside of the classroom by the individual student teams.
* Emphasize the quality of the physics principals and clarity of communication over the speed and distance outcomes of the Mousetrap car.
 |
| *Please provide enough information and details so the teacher can deliver the lesson.*This lesson follows Lesson #6. In Lesson #6 students engaged in an investigation and extension activities to learn about the general conservation of energy principal and the special case of conservation of mechanical energy principal.Lesson #7 begins with a discussion of the project. Ground rules, assessment rubrics and team dynamics are discussed and clarifying questions are responded to. During the activity the teacher ‘s role is to facilitating on-task behavior, answer “clarification” questions, probe student thinking, remind students of past knowledge, and to respond to student questions, as best as possible, with guided questions (i.e., the discourse can be generally characterized as “Socratic.”). Leading questions from the teacher may stretch the student’s thinking significantly or may contain hints and only require a small leap of thinking from the student. The instructor will use their best judgment based on the needs of their individual students and the students’ ability to tolerate potential frustration during this back-and-forth questioning. |
| *Extended Learning/Practice (homework)*Optional Extension: Research project that relates big science ideas, content, skills to a real world problem such as “Are we running out of energy?” |
| Closure*Review outcomes of this lesson:* K1: The causal agent for the transfer of energy (work) is the result of force acting over a displacement (actually the component of the force in the direction of the displacement (e.g., W= **F**average •**∆d**).K3. The relationship between energy of motion (kinetic energy), mass and speed (qualitatively and quantitatively – larger speed 🡺 greater KE and KE ~ v2; large mass 🡪 greater K and KE ~ m)K4. Potential energy can be classified based on the type of force field in which an object is placed (e.g. electro-magnetic potential energy (chemical potential energy and elastic potential energy are specific examples of electro-magnetic potential energy),K5. Energy can be transferred and transformed between and within potential energy and kinetic energy.K6. Conservation of energy means the total change of energy in any system is equal to the sum of the energy transferred into the system plus out of the system.K7. The change in potential energy of an object can be determined directly from the work done by the force field when an object is displaced in the field (e.g., ∆PE = **- F**field,avg • **∆s**).K8. The change in gravitational potential energy for an object displaced in the near Earth gravitational field (∆PE=mg∆h) and the change in elastic (electromagnetic) potential energy due to a compressed/stretched spring (∆PE=.5ks22-.5ks12) follows directly from the principle that ∆PE = **- F**field,avg • **∆s**.K9. A force field gives rise to a conservative force if the work to change the object’s position (displace the object) within the force field is the same no matter the physical path taken to make the displacement.K10. When only conservative forces act on a system, ∆KE = -∆PE or Total Mechanic Energy remains constant over time.S1: Choose appropriate technology to study energy.S2: Use the formula W = Faverage •∆d to analyze and compute the work done on an object by a force.S4. Use the formula KE=.5mv2 to compute the kinetic energy of an object.S5. Use the formula PE=mgh to compute the potential energy of the Earth-object system when an object is located near the Earth’s surface (where h is the distance from an arbitrary reference point often chosen to be the Earth’s surface or the closes point to the Earth’s surface an object gets for a specific problem).S6. Use the formula PE=.5ks2 to compute the potential energy of a Hooke’s law spring.S7. Use the strategy of computing the area under a force-displacement graph to determine the work done by a force.S8. Use the formula Wexternal + Wnon-conservative = ∆KE + ∆PE to analyze and solve problems of energy transfer.S9. Articulate how energy is transferred between systems.S10. Use the concept of conservation of energy to predict and describe system (position and speed) behavior.S11. Use data gathered through experiments to analyze and draw conclusions.S12. Use evidence and scientific and mathematical reasoning to communicate experimental results and to make claims.*Preview outcomes for the next lesson:* |

Teacher Reflection (to be completed after lesson)

|  |
| --- |
| What went well in this lesson?Did all students accomplish the outcome(s))? What evidence do I have?What would I do differently next time? |

**Curriculum Embedded Performance Assessment (CEPA)**

Mousetrap Car Energy Transfer Engineering



**Goal:** Construct a mousetrap car that uses a spring as a power source and meets specified construction and performance criterion.

**Role:** Engineering team working for the “Extreme Toys R’US” company.

**Audience:** The product you are designing is targeted for sale to boys and girls between the ages of 9 and 13.

**Scenario:** The CEO has assigned your engineering team along with two other engineering teams the task of designing a “mousetrap” car for sale to boys and girls ages 9-13. The teams are given specific performance criterion and design/construction criterion.

**Performance criterion** are: (1) Your vehicle is to maximizes the conversion of potential energy to kinetic energy at launch (i.e., |∆KElaunch/∆PElaunch| is as close to 1 as possible); (2) minimizes the net frictional force that acts on the car following launch (i.e., |∆KEcoast/∆xcoast| is as close to 0J/m or 0N as possible) and (3) will move at least 1-meter following launch.

**Design/construction criterion** are: (1) The total cost of the car must not exceed $20; (2) the energy source for the “mousetrap” car is one standard mousetrap supplied by the hardware division of Extreme Toys R’US; (3) the vehicle must be able to fit into a rectangular container no larger than 40cm by 15cm by 15cm; (4) the car can not have more than four wheels; (5) company safety and (6) team work protocols must be followed during all engineering design phases of the work; and (7) the vehicle evaluation’s will be partially determined by the aesthetics rating of two separate consumer focus groups (one comprised of all males and one comprised of all females within the target audience age span).

The team that produces a vehicle that meets all design/constructive criterion (1) through (4) and has the highest score on the “Standards & Criterion for Success” rubric found below will be awarded an end of year “product development” bonus.

**Product:**

• A working vehicle.

• Write a “performance report” tracing ***qualitatively*** and ***quantitatively*** the transfer of energy that takes place during launch and during the subsequent coast.

• Write a “design manual” outlining considerations for constructing a mousetrap car that will meet the specified construction criterion (cost constraints, one standard mousetrap, size constraints, no more than 4-wheels) and performance criterion (maximize transfer of energy from the mousetrap mechanism to the kinetic energy of the car at launch and minimize the net frictional force acting on the car following launch). The design manual will also include schematic diagram(s) illustrating all major components of the final working vehicle.

**Standards & Criterion for Success:** The project will be assessed on the following criteria:

*Miscellaneous (total 20 points)*

• Vehicle does not meet design criterions (1) through (4) – NOT eligible for bonus and -20 pts.

• Vehicle works and following launch moves forward at least 1-meter – score of 0 or 5 pts.

• Average aesthetics rating of the two consumer test groups - maximum score of 5 pts.

• Design team follows all company safety rules during project – maximum score of 5 pts.

• Design team follows company teamwork practices during project – maximum score of 5 pts.

*Performance Report (total 60 points)*

• Maximizes energy transfer during launch with clearly written evidence in support of claim - <35% = 0 pts.; ≥35% 2 pt.; ≥40% = 4 pts.; ≥45% = 6 pts.; ≥50% = 8 pts.; ≥60% = 10 pts.

• Clarity and correctness of written evidence that support energy transfer claim – 25 pts.

• Minimizes net frictional force during coast (based on comparison between all engineering teams) – maximum score of 10 pts.

• Clarity and correctness of written evidence that supports frictional force claim – 15 pts.

*Design Manual (20 points)*

• Clarity and completeness of schematic diagram of car and key components – maximum score of 10 pts.

• Clarity and completeness of written discussion of design considerations – maximum score of 10 pts.

• Bonus Points: Car travels 5 m or more – bonus of 5 points

 Car travels the furthest of all tested cars – bonus of 5 points

Energy Unit

Mousetrap Car Performance Assessment

*Building Confidence through Competency*

**Goal:** Construct a mousetrap car that uses a spring as a power source and meets specified construction and performance criterion.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Criterion | Specific Criterion | Potential Value | Score Achieved | Comments |
| **Design Misc.** | Cost (≤$20) | 0 or -20 |  |  |
|  | Energy Source (1-Standard Mousetrap) | 0 or -20 |  |  |
|  | Size (40x15x15)cm | 0 or -20 |  |  |
|  | Wheels ≤4 | 0 or -20 |  |  |
|  | Travels ≥1m | 0 or 5 |  |  |
|  | Safety Rules | 0 - 5 |  |  |
|  | Team Protocols | 0 - 5 |  |  |
|  | Aesthetics | 0 - 5 |  |  |
| **Design Manual** | Schematics | 0 - 10 |  |  |
|  | Design Considerationand Analysis | 0 - 10 |  |  |
| **Performance** | Max. Energy Transfer|∆KElaunch/∆PElaunch| | 0 - 10 |  |  |
|  | Evidence of PE | 0 - 10 |  |  |
|  | Evidence of KE | 0 - 10 |  |  |
|  | Evidence of Ratio | 0 - 5 |  |  |
|  | Minimize Friction|∆KEcoast/∆xcoast| | 0 - 10 |  |  |
|  | Evidence ∆KE | 0 - 10 |  |  |
|  | Evidence of Ratio | 0 - 5 |  |  |
| **Totals** | **All Mandatory Criterion** | **0 - 100** |  |  |
| **Bonus Misc.** | Distance ≥5m | 0 or 5 |  |  |
|  | Furthest Distance | 0 or 5 |  |  |
| **Grand Totals** | **Plus Bonus** | **0 - 110** |  |  |

APPENDIX I

# Interactive Laboratory Experience/Interactive Lecture Demonstration

Procedure

 

This 8-step pedagogy intellectually and actively engages students in learning concepts in physics. The Interactive Laboratory Experience (ILE/ILD1) moves students through a learning cycle from soliciting student pre-conceptions, to engaging in animated scientific peer debate, to leaning from nature, confronting initial conceptions with experimental observations and making connections to the student’s world outside the classroom and laboratory.

**1. The Exploration:** The instructor will describe and demonstrate as much of the experiment as he/she can without giving away the results. The exploration should be clearly articulated by the instructor. Students ask “points of clarification” questions.

**2. Individual Prediction:** Ask students to record individual predictions on a prediction handout sheet. *Step-2 encourages individual risk taking and uncovers preconceptions.*

**3. Small Group Discussion:** Have the class engage in small group discussions (or within laboratory group discussion). *Step-3 encourages listening skills, communication skills, collegial debating, and self-reflection of preconceptions.*

**4. Large Group Discussion:** Elicit common student predictions from the whole class (or multi laboratory group discussion). Do not judge the merit of the predictions. Encourage groups that did not volunteer a prediction to make one or comment briefly on one they might agree with that is already on the board. *Step-4 documents the class (or laboratory groups’) predictions, allows a broader sharing of ideas and preconceptions and encourages the engagement of all students.*

**5. Modified Prediction:** Students can now revise their predictions, and should record any modifications on their prediction handout sheet. *Step-5 further encourages reflective thinking*.

**6. “Nature Speaks”- Collect Data:** The experiment is carried out.

**7. Record the Results and Class Discussion:** Ask students to describe the results and discuss results in the context of the experiment. Encourage dialog between students and elicit from them comments about their thought process. Discussions around the similarities and differences between the predicted results and the experimental results are encouraged. Students fill out the results handout sheet and complete any additional extension activities.

**8. Similar Situations:** Discuss analogous physical situations that are based on the same concept or principle just explored. *Step-8 encourages making connections to the students’ world.*