A Slippery Slope

Overview

Description

In this activity, students will use a plane to study motion with constant acceleration as blocks of various materials slide down the plane at various angles of incline. The assignment assesses students' ability to understand concepts such as potential energy, kinetic energy, and the conversion of mechanical energy to other forms (via friction). Students will then relate those to kinematics results and to formulate predictions for how much mechanical energy is lost for specific block materials based on these understandings.

Final Product: Students will work in groups and use the data collected from the activity to calculate the acceleration value and also the final speed of each block. Using this information they will then create and test formulas to predict the sliding times for randomly chosen slopes and distances. Groups will then compete against their peers in Downhill Time Trials to see whose formula made the best predictions. Students will write and submit an individual report detailing the reasoning behind their experiments, predictions, and interpretation of final results. Each report will include relevant data, tables, equations, diagrams, and answers to the questions in the Drawing Conclusions section of the assignment.

Subject

Physics

Task Level

Grade 11

Objectives

Students will:

- Understand the concepts of gravitational potential and kinetic energy.
- Work collaboratively with peers to plan for the activity.
- Demonstrate familiarity with length scales, speed, and motion under constant acceleration.
- Work collaboratively to experiment with blocks of various materials accelerating down a sloped track at various incline angles.
- Estimate the amount of mechanical energy lost to thermal energy via friction.

- Communicate an initial understanding of key principles regarding motion down an incline.
- Formulate a way to predict the behavior (sliding time) for an object of known material and mass, along a track of known length and incline angle.
- Communicate understanding of key principles regarding motion down an incline, the concepts of potential and kinetic energy, and the law of conservation of energy.

Preparation

- Make various linear tracks and inclined planes, scales, containers, meter sticks, ice cubes, blocks of various materials, clocks or stopwatches, and other equipment available as necessary. Provide a way to handle and store the ice cubes (tongs, containers, towels, cooler, or freezer) to minimize melting.
- Make a copy of the Student Notes pages for each student.

Prior Knowledge

Students should understand concepts related to motion with constant acceleration (kinematics), mechanical energy, friction, thermal energy and the conservation of energy. They should have experience measuring and calculating distances, lengths, times, and masses as well as have a basic knowledge of mathematics and skills consistent with high school algebra, geometry, and trigonometry.

Students do *not* need to understand concepts related to work and frictional forces, coefficients of friction, normal forces, etc. for success in this assignment. Students can simply consider energy loss per meter of track and how that changes for various angles of incline.

Key Concepts and Terms

- Angle of inclination
- Conservation of mechanical energy
- Friction
- Gravitational interaction
- Inclined plane
- Kinetic energy
- Mechanical energy
- Motion
- Potential energy

Time Frame

This assignment generally requires two or three hours of in-class time, though this can be reduced if different groups of students collect different subsets of data and then pool all of the data together in the end. The activity may also require students to do some preparation outside of class depending on your requirements. Plan for students to spend an additional two hours to complete the written portion of the assignment. This assignment can be modified to meet the needs of different classroom schedules and student ability levels.

Instructional Plan

Getting Started

Learning Objectives

Students will:

- Understand the concepts of gravitational potential and kinetic energy.
- Work collaboratively with peers to plan for the activity.

Procedure

1. Explain the expectations of the task to students. They will use a linear track to experiment with the behavior of sliding blocks on an inclined plane, in order to make accurate predictions of a block's speed at the bottom of the incline and the mechanical energy lost (if any) to friction in that process.
2. Ask them to read the instructions and plan their experiments carefully to be sure they prepare for the proper types and numbers of sliding trials.
3. Ask students to consider carefully how they will use ice cubes to model very low-friction ("frictionless") sliding.
4. Remind all students that as ice melts, it loses mass; the melt water drips away onto hands, table, track, etc. while being weighed and handled. How will they minimize this? Encourage them to think about when ice is the most slippery so that they can best model frictionless conditions.
5. Ask students to note that blocks do not start to slide until the track is inclined more and more. At what angles do they finally slip?
6. Show students the materials available to them for this task, and remind them of their basic knowledge of kinematics and energy. Have them begin brainstorming in small groups as to how they are going to use their knowledge and their sliding data to formulate a mathematical rule or equation to allow them to predict a given block's slide time on a given slope.

Investigating

Learning Objectives

Students will:

- Demonstrate familiarity with length scales, speed, and motion under constant acceleration.
- Work collaboratively to experiment with blocks of various materials accelerating down a sloped track at various incline angles.

Procedure

1. Allow students to experiment and gather data with various blocks sliding down a surface inclined at various angles.
2. Encourage students to use their basic knowledge of kinematics, kinetic energy, and gravitational potential energy to calculate as well as observe these quantities at specific moments during the motion down the inclined plane.
3. Ensure students recognize the following.
   a. If friction is negligible, they can use the law of conservation of mechanical energy to calculate the kinetic energy and thus the speed of a known mass at any point along the incline.
   b. If friction does exist, they can use the same considerations to estimate the amount of mechanical energy lost to friction when the mass reaches the bottom of the incline—again by observing the speed of the mass at that point.

Drawing Conclusions

Learning Objectives

Students will:

- Estimate the amount of mechanical energy lost to thermal energy via friction.
- Communicate an initial understanding of key principles regarding motion down an incline.
- Formulate a way to predict the behavior (sliding time) for an object of known material and mass, along a track of known length and incline angle.
- Communicate understanding of key principles regarding motion down an incline, the concepts of potential and kinetic energy, and the law of conservation of energy.

Procedure

1. Ask each group to report to you their formula for predicting the sliding time for a given mass, slope incline, and length for three different block materials.
2. Have each student group test the efficacy of their formula. Start by selecting (at random) one mass of each of three (non-ice) materials. For each mass, select a random (but appropriate) incline and slope length. Have group post on the board their predictions for sliding time of the mass.
3. Have the class discuss the accuracy of all predictions and select the most accurate group.

4. Ask the students in all groups to give a brief oral explanation of the reasoning behind their formula and predictions. Make sure groups describe what accounted for their success or what they would do differently next time.
5. Ask students in each group to submit an individual report that explains all sliding trials, analyses and predictions, and final results. Each report should include relevant raw data, data tables, equations, diagrams, reasoning used, and address all questions asked in the Drawing Conclusions section of the assignment.

Scaffolding/Instructional Support

The goal of scaffolding is to provide support to encourage student success, independence, and self-management. Instructors can use these suggestions, in part or all together, to meet diverse student needs. The more skilled the student, however, the less scaffolding that he or she will need. Some examples of scaffolding that could apply to this assignment include:

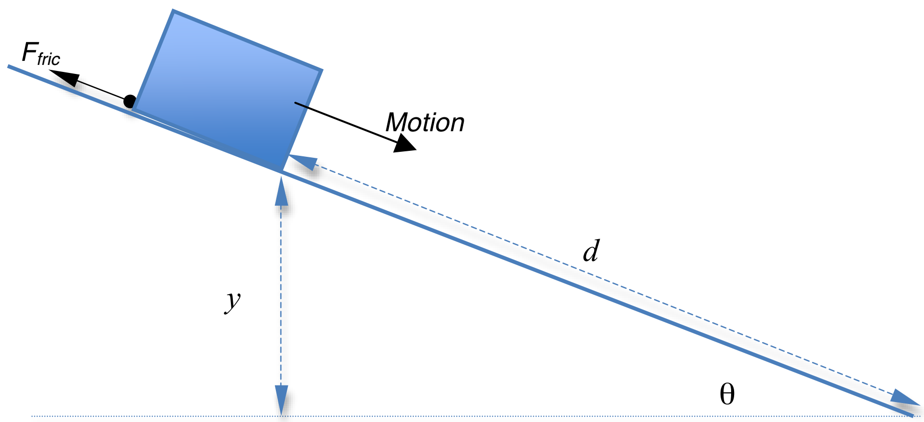
- Remind struggling students about the basics of kinematics, especially the assumptions of constant acceleration and the various equations.
- Remind struggling students of the basics of trigonometry, including how to calculate an angle by using two known sides of a right triangle.
- Remind struggling students how to calculate kinetic and gravitational potential energy. If needed, give them a list of equations.
- Remind all students that experiments are repeated with just one variation at a time, particularly when addressing the issues of mass, angle dependency, and the critical angle for frictional "first-slipping."
- Control the use of equations. If needed, write useful equations on the board or create an equation sheet to hand out to the class.
- If needed, provide data tables to students (see example below):

Material: ______________________

Angle	**M_1(kg)**	**M_2(kg)**	**M_3(kg)**
θ_1			
θ_2			
θ_3			
θ_4			
θ_5			

Solutions

The information below is intended to help you assess students' final work products. It may not represent all possible strategies and ideas. The accompanying scoring guide provides specific examples of ways a student might demonstrate content understanding and mastery of cross-disciplinary skills.



Students should recognize that the full value of *g* (the gravitational acceleration at the earth's surface) is not applicable directly in these kinematics equations because the mass is not in vertical free-fall—it's descending at an angle and may also be under the influence of friction.

Nevertheless, the students should be able to arrive at the reasonable assumption, after observing the behavior of the sliding block, that the acceleration is a steady value for any given angle of incline. Using this assumption, they should be able calculate the final speed, v_f, of the mass as it reaches the bottom of the incline. They should calculate this using the kinematic relation that (while still assuming a constant value for the acceleration) does not require that the acceleration value to be known:

$$x_f - x_i = \frac{1}{2}(v_i + v_f)t$$

Notice that the right hand side of this equation is simply the average velocity times time. In our experiment both x_i and v_i are zero, solving for v_f is easy:

$$v_f = \frac{2x_f}{t} = \frac{2d}{t}$$

Students should then be able to use that result to calculate the kinetic energy of the mass at the bottom of the slope:

$$K_f = \tfrac{1}{2}mv_f^{\,2} = \tfrac{1}{2}m\left(2d/t\right)^2 = 2md^2/t^2$$

And since the mass started from rest at the top of the slope, $v_i = 0$:

$$K_i = \tfrac{1}{2}mv_i^{\,2} = \tfrac{1}{2}m(0)^2 = 0$$

Likewise, students should be able to find the change in gravitational potential energy as a result of the motion of the mass by assigning a zero reference point at the bottom of the slope, so that $U_{grav.f} = mgh_f = mg(0) = 0$. The initial value is then $U_{grav.i} = mgh_i = mgy$ (where g is the local gravitational acceleration value ≈ 9.8 m/s^2).

Putting all this together yields the analysis of the change in total mechanical energy as a result of the motion:

$$E_{mech.f} = K_f + U_{grav.f} = 2md^2/t^2 + 0 = 2md^2/t^2$$

$$E_{mech.i} = K_i + U_{grav.i} = 0 + mgy = mgy$$

For the case of a sliding ice cube, this difference should be only slight. But with the other sliding blocks, the difference should be significant. Hopefully, students will conclude from this that the law of conservation of mechanical energy applies only in the absence of friction.

They should also recognize that, if friction does exist, the block will begin to slide only when the inclination angle is greater than or equal to a certain critical angle that depends on the material(s) that the block and the incline are made of (but not the mass of the block).

Drawing Conclusions

1. The maximum acceleration that can be attained is the acceleration due to gravity.

   From Newton's second law, the net force (m·g·sinθ minus the force of friction) is proportional to the acceleration. Different types of materials have different surface roughness, and therefore have different coefficients of friction. So, the higher the surface roughness (frictional force), the lower the net force (acceleration). Acceleration will give information about the relative nature of the friction between the track and each type of material used.

2. Students should observe that the block moves only when the component of its weight along the plane is equal to the frictional force. In mathematical terms:

   $m \cdot g \cdot \sin\theta - F_{fric} = 0$. Thus $\theta = \sin^{-1}(F_{fric}/mg)$.

   Only the nature of the surface of the material will affect the minimum angle. It is important to recognize that friction depends on the normal force (frictional force = m·g·cos θ × coefficient of friction), thus the mass cancels out and the critical angle depends only on the coefficient of friction.

3. Total mechanical energy is not conserved, except in the case of the ice cube. Only the type of material matters since its surface roughness will determine the magnitude of the frictional force.

   With the other materials, energy is lost as thermal energy due to friction. As the sliding object rubs against the track molecules in the object and the track will bump into each other making the molecules jiggle vigorously. This rubbing transfers some of the kinetic energy of the object to "jiggling energy" of the molecules. This "jiggling energy" is known as thermal energy and is related to temperature.

4. As the cube slides down the slope, some of the potential energy is converted to kinetic energy and thermal energy (due to friction). The energy equation is give by:

   $m \cdot g \cdot y_i - 1/2 m v_f^2 = F_{fric} \times$ distance. This equation can be re-written as: $g \cdot y_i - 1/2 v_f^2 = \mu \cdot g \cdot \cos\theta \times$ distance, which is independent of mass (μ is the coefficient of friction).

   The equation holds for both steep and shallow angles. In words this equation could be written as "initial gravitational potential energy – final kinetic energy = work" or "initial gravitational potential energy – final kinetic energy = thermal energy".

5. We can use conservation of energy to predict the time required for a block to slide down the track. Conservation of energy tells us that $E_{mech,i} = E_{mech,f} + E_{thermal}$. Using the expressions in the last section this can be written $mgy_i = 2md^2/t^2 + E_{thermal}$. $E_{thermal}$ can be estimated from the experiments and $y_i = d\sin\theta$.

   An alternative approach would be to use the kinematic equation $d = 1/2at^2$. In this case the student would need to use his or her data from the experiment to estimate the acceleration of the chosen object at the chosen angle.

TCCRS Cross-Disciplinary Standards Addressed

Performance Expectation	Getting Started	Investigating	Drawing Conclusions
I. Key Cognitive Skills			
A.1. Engage in scholarly inquiry and dialogue.	✓		✓
B.1. Consider arguments and conclusions of self and others.	✓		✓
B.2. Construct well-reasoned arguments to explain phenomena, validate conjectures, or support positions.	✓		✓
B.3. Gather evidence to support arguments, findings, or lines of reasoning.		✓	
B.4. Support or modify claims based on the result of an inquiry.			✓
C.1. Analyze a situation to identify a problem to be solved.	✓	✓	
C.2. Develop and apply multiple strategies to solve a problem.		✓	
C.3. Collect evidence and data systematically and directly relate to solving a problem.		✓	✓
D.1. Self-monitor learning needs and seek assistance when needed.	✓	✓	✓
D.2. Use study habits necessary to manage academic pursuits and requirements.	✓	✓	✓
D.3. Strive for accuracy and precision.	✓	✓	✓
D.4. Persevere to complete and master tasks.	✓	✓	✓
E.1. Work independently.			✓
E.2. Work collaboratively.	✓	✓	✓
F.3. Include the ideas of others and the complexities of the debate, issue, or problem.	✓	✓	✓
II. Foundational Skills			
B.1. Write clearly and coherently using standard writing conventions.			✓
C.5. Synthesize and organize information effectively.		✓	✓
C.6. Design and present an effective product.		✓	✓

D.1. Identify patterns or departures from patterns among data.		✓	✓
D.2. Use statistical and probabilistic skills necessary for planning an investigation and collecting, analyzing, and interpreting data.		✓	✓
D.3. Present analyzed data and communicate findings in a variety of formats.			✓
E.1. Use technology to gather information.		✓	
E.2. Use technology to organize, manage, and analyze information.			✓
E.3. Use technology to communicate and display findings in a clear and coherent manner.			✓
E.4. Use technology appropriately.		✓	✓

TCCRS Science Standards Addressed

Performance Expectation	**Getting Started**	**Investigating**	**Drawing Conclusions**
I. Nature of Science: Scientific Ways of Learning and Thinking			
A.2. Use creativity and insight to recognize and describe patterns in natural phenomena.	✓	✓	✓
A.4. Rely on reproducible observations of empirical evidence when constructing, analyzing, and evaluating explanations of natural events and processes.		✓	✓
B.1. Design and conduct scientific investigations in which hypotheses are formulated and tested.		✓	
C.1. Collaborate on joint projects.	✓	✓	✓
C.3. Demonstrate skill in the safe use of a wide variety of apparatuses, equipment, techniques, and procedures.		✓	
D.3. Demonstrate appropriate use of a wide variety of apparatuses, equipment, techniques, and procedures for collecting quantitative and qualitative data.		✓	

E.1. Use several modes of expression to describe or characterize natural patterns and phenomena. These modes of expression include narrative, numerical, graphical, pictorial, symbolic, and kinesthetic.		✓	✓
E.2. Use essential vocabulary of the discipline being studied.	✓	✓	✓
II. Foundation Skills: Scientific Applications of Mathematics			
A.1. Understand the real number system and its properties.		✓	✓
A.3. Understand ratios, proportions, percentages, and decimal fractions, and translate from any form to any other.		✓	✓
A.4. Use proportional reasoning to solve problems.		✓	✓
A.5. Simplify algebraic expressions.			✓
A.6. Estimate results to evaluate whether a calculated result is reasonable.		✓	✓
A.7. Use calculators, spreadsheets, computers, etc., in data analysis.		✓	✓
B.1. Carry out formal operations using standard algebraic symbols and formulae.			✓
B.2. Represent natural events, processes, and relationships with algebraic expressions and algorithms.		✓	✓
C.3. Understand basic trigonometric principles, including definitions of terms such as sine, cosine, tangent, cotangent, and their relationship to triangles.	✓	✓	✓
C.4. Understand basic geometric principles.		✓	✓
F.1. Select and use appropriate Standard International (SI) units and prefixes to express measurements for real-world problems.		✓	✓
F.2. Use appropriate significant digits.		✓	✓
III. Foundation Skills: Scientific Applications of Communication			
A.1. Use correct applications of writing practices in scientific communication.			✓

B.2. Set up apparatuses, carry out procedures, and collect specified data from a given set of appropriate instructions.		✓	
B.3. Recognize scientific and technical vocabulary in the field of study and use this vocabulary to enhance clarity of communication.	✓	✓	✓
VIII. Physics			
B.1. Understand how vectors are used to represent physical quantities.	✓	✓	✓
B.2. Demonstrate knowledge of vector mathematics using a graphical representation.			✓
B.3. Demonstrate knowledge of vector mathematics using a numerical representation.		✓	✓
C.1. Understand the fundamental concepts of kinematics.	✓	✓	✓
C.2. Understand forces and Newton's Laws.	✓	✓	✓
D.1. Understand potential and kinetic energy.	✓	✓	✓
D.2. Understand conservation of energy.	✓	✓	✓

TEKS Standards Addressed

A Slippery Slope - *Texas Essential Knowledge and Skills (TEKS): Physics*
112.39.c.1. Scientific processes. The student conducts investigations, for at least 40% of instructional time, using safe, environmentally appropriate, and ethical practices. These investigations must involve actively obtaining and analyzing data with physical equipment, but may also involve experimentation in a simulated environment as well as field observations that extend beyond the classroom. The student is expected to: 112.39.c.1.A. demonstrate safe practices during laboratory and field investigations.
112.39.c.2. Scientific processes. The student uses a systematic approach to answer scientific laboratory and field investigative questions. The student is expected to: 112.39.c.2.B. know that scientific hypotheses are tentative and testable statements that must be capable of being supported or not supported by observational evidence. Hypotheses of durable explanatory power which have been tested over a wide variety of conditions are incorporated into theories. 112.39.c.2.C. know that scientific theories are based on natural and physical phenomena and are capable of being tested by multiple independent researchers. Unlike hypotheses, scientific theories are well-established and highly-reliable explanations, but may be subject to change as new areas of science and new technologies are developed 112.39.c.2.D. distinguish between scientific hypotheses and scientific theories 112.39.c.2.E. design and implement investigative procedures, including making observations, asking well-defined questions, formulating testable hypotheses, identifying variables, selecting

A Slippery Slope - *Texas Essential Knowledge and Skills (TEKS): Physics*
appropriate equipment and technology, and evaluating numerical answers for reasonableness. 112.39.c.2.F. demonstrate the use of course apparatus, equipment, techniques, and procedures, including multimeters (current, voltage, resistance), triple beam balances, batteries, clamps, dynamics demonstration equipment, collision apparatus, data acquisition probes, discharge tubes with power supply (H, He, Ne, Ar), hand-held visual spectroscopes, hot plates, slotted and hooked lab masses, bar magnets, horseshoe magnets, plane mirrors, convex lenses, pendulum support, power supply, ring clamps, ring stands, stopwatches, trajectory apparatus, tuning forks, carbon paper, graph paper, magnetic compasses, polarized film, prisms, protractors, resistors, friction blocks, mini lamps (bulbs) and sockets, electrostatics kits, 90-degree rod clamps, metric rulers, spring scales, knife blade switches, Celsius thermometers, meter sticks, scientific calculators, graphing technology, computers, cathode ray tubes with horseshoe magnets, ballistic carts or equivalent, resonance tubes, spools of nylon thread or string, containers of iron filings, rolls of white craft paper, copper wire, Periodic Table, electromagnetic spectrum charts, slinky springs, wave motion ropes, and laser pointers. 112.39.c.2.G. use a wide variety of additional course apparatus, equipment, techniques, materials, and procedures as appropriate such as ripple tank with wave generator, wave motion rope, micrometer, caliper, radiation monitor, computer, ballistic pendulum, electroscope, inclined plane, optics bench, optics kit, pulley with table clamp, resonance tube, ring stand screen, four inch ring, stroboscope, graduated cylinders, and ticker timer. 112.39.c.2.H. make measurements with accuracy and precision and record data using scientific notation and International System (SI) units. 112.39.c.2.I. identify and quantify causes and effects of uncertainties in measured data. 112.39.c.2.K. communicate valid conclusions supported by the data through various methods such as lab reports, labeled drawings, graphic organizers, journals, summaries, oral reports, and technology-based reports. 112.39.c.2.L. express and manipulate relationships among physical variables quantitatively, including the use of graphs, charts, and equations.
112.39.c.3. Scientific processes. The student uses critical thinking, scientific reasoning, and problem solving to make informed decisions within and outside the classroom. The student is expected to: 112.39.c.3.A. in all fields of science, analyze, evaluate, and critique scientific explanations by using empirical evidence, logical reasoning, and experimental and observational testing, including examining all sides of scientific evidence of those scientific explanations, so as to encourage critical thinking by the student. 112.39.c.3.F. express and interpret relationships symbolically in accordance with accepted theories to make predictions and solve problems mathematically, including problems requiring proportional reasoning and graphical vector addition.
112.39.c.4. Science concepts. The student knows and applies the laws governing motion in a variety of situations. The student is expected to: 112.39.c.4.A. generate and interpret graphs and charts describing different types of motion, including the use of real-time technology such as motion detectors or photogates. 112.39.c.4.B. describe and analyze motion in one dimension using equations with the concepts of distance, displacement, speed, average velocity, instantaneous velocity, and acceleration. 112.39.c.4.D. calculate the effect of forces on objects, including the law of inertia, the relationship between force and acceleration, and the nature of force pairs between objects. 112.39.c.4.E. develop and interpret free-body force diagrams.

A Slippery Slope - *Texas Essential Knowledge and Skills (TEKS): Physics*
112.39.c.6. Science concepts. The student knows that changes occur within a physical system and applies the laws of conservation of energy and momentum. The student is expected to: 112.39.c.6.A. investigate and calculate quantities using the work-energy theorem in various situations. 112.39.c.6.B. investigate examples of kinetic and potential energy and their transformations. 112.39.c.6.C. calculate the mechanical energy of, power generated within, impulse applied to, and momentum of a physical system 112.39.c.6.D. demonstrate and apply the laws of conservation of energy and conservation of momentum in one dimension. 112.39.c.6.F. contrast and give examples of different processes of thermal energy transfer, including conduction, convection, and radiation.

A Slippery Slope

Introduction

When you slide down a hill on skis, a snowboard, or a sled, you go faster when the slope is slippery with snow or ice than you would on bare ground. Why? It's the same hill, and you have the same amount of gravitational energy to spend going from top to bottom every time. Why don't you have the same kinetic energy (indicated by your speed) at the bottom in every case? Can you use your knowledge of physics to resolve these issues and win the Downhill Time Trials?

The Problem

You and your team will be given a linear track that you can tilt at any given angle to change the steepness. You will also be given blocks made of various materials. You will then conduct experiments to see how quickly each block slides to the bottom of the incline when it is set at different angles. You will need to use various tools to measure masses, lengths, angles, and times. You will also need to use what you already know about motion with constant acceleration (kinematics), kinetic energy and gravitational potential energy. You will combine your measurements and knowledge to determine an equation or formula to predict the time needed by an object of a given material to slide down an incline of a given length and angle.

After you have determined such a formula for several different objects, your group will compete in the Downhill Time Trials with other groups to see who can best predict the motion of their objects.

Directions

Getting Started

1. Watch and listen as your instructor introduces the basic equipment and demonstrates the use of meters and balances in class. You will need to know how to measure lengths, heights, and masses and how to calculate angles and speeds. Recall that the kinetic energy of a given object depends on its mass and its speed. Its gravitational potential energy depends on its mass, the acceleration due to gravity, and its height.

2. Be prepared to measure times, masses, heights, lengths, and angles during your experiments. You will use your data in the calculation of the speed, and the kinetic, potential, and mechanical energies of the sliding object at the start

and end of its motion down the incline. You will need to use equations you have learned to calculate motion under constant acceleration.

3. You are going to investigate the sliding motions of several objects, each of which has a different degree of friction with the surface of the track. One of these objects will be an ice cube (or small chunk of ice) and will serve as the model for essentially frictionless sliding. Be prepared to think and plan how you're going to use an ice cube as a sliding object without letting it melt so much that your measurements of its mass are inaccurate! Brainstorm answers to the following questions with your group.
   a. When is ice more sticky? When is it more slippery?
   b. How will you handle the ice to prevent melting?
   c. When and how will you measure its mass?

Investigating

1. Be sure to document your group's progress, all data from all trials, and all your thinking and reasoning as you observe, investigate and predict the motion of the object.
2. Read through all instructions below. Note the basic procedures and also the data tables you will need to prepare. Proceed when you are ready. **For each of four types of objects (ice plus three other materials), follow steps 3 through 8.**
3. Level the linear track. Measure and mark off some length along it (you may choose the length), and incline it at a slight angle. Measure that angle.
4. Release the object, allowing it to slide freely from the starting position you marked. Note the time it takes from the start of its motion until it passes the end mark. If it doesn't slide at all, make a note of this. Then set and measure a new, steeper angle at which the object will slide.
5. Measure the mass of the object.
6. Repeat steps 3 through 5 three more times using the same object and using progressively steeper angles. (You don't need to re-measure the object's mass, unless it is ice. Why?)
7. Repeat steps 3 through 6, using an object made of the same material as before but a different (2^{nd}) mass.
8. Repeat steps 3 through 6, using an object made of the same material as before but a different (3^{rd}) mass.
9. When your investigations are complete, you should have a total of 48 sets of slide data recorded. The data sets include: blocks made of four different

materials (including ice); and for each material, three different masses; and for each mass, four different angles of incline.

Drawing Conclusions

1. Assuming that each object slides with constant acceleration, use your data to calculate the acceleration value and also the final speed (i.e., the speed with which the object reaches the end mark on the slope). What acceleration value would be the maximum possible for any case? Knowing something about the nature of the friction between the track and each type of material, do the acceleration values make sense, relative to one another?

2. What did you observe about the minimum angle necessary for each type of material to start sliding? Did the mass of the block affect this—or just the material?

3. Would you say that mechanical energy (recall that mechanical energy is the sum of kinetic energy and gravitational potential energy) was conserved as the objects slid down their slopes? In all cases? Any cases? Use numbers and equations to support your claims about when mechanical energy is or is not conserved. Also write a few sentences to explain your equations. (i.e., What does each side of the equation represent?)

4. In any case where mechanical energy was apparently not conserved, what happened to that energy? Where did it go, and in what form or type? Explain this thoroughly. Try to write an equation that would represent conservation of energy (total energy, not just mechanical energy) for these cases. Explain in words what each term in your equation represents.

5. For each non-ice material and object mass, work with your group to find a mathematical equation or formula for how the angle and length of the track affects the sliding time of the object. How might you do this? Does your pattern hold for even steeper or shallower angles? Greater or lesser masses? Report to your teacher when you've identified one equation or formula for each of the three non-ice materials. (Hint: You can use mostly kinematics equations or mostly conservation of energy equations but either way there will be one value that will need to be estimated using the data from your.)

6. When all groups have reported, your teacher will randomly select one object from among your non-ice materials. He or she will conduct a Downhill Time Trial with that object set on three different inclines and slope lengths. Before the Trial, your group will be given the inclines and slope lengths that will be tested. Post on the board a prediction for how much time it will take for each object to reach the bottom of the incline. Your will measure the actual times and compare them to each set of predictions. The winner of the Downhill

Time Trials award will be the group with the best success at predicting the three trials.

7. Prepare and submit a final written report explaining your group's work and results, including all relevant data, tables, diagrams, equations, and reasoning used. Be sure to address all questions listed throughout the assignment.