DEVELOPING K-6 ENGINEERING CURRICULUM IN AN URBAN PUBLIC SCHOOL SYSTEM

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K-12 Session

Massachusetts introduced technology and engineering into its K-12 curriculum frameworks in 2001. With funding from the National Science Foundation (NSF), Worcester Polytechnic Institute (WPI) and the Worcester Public Schools (WPS) have formed a partnership to develop technology/engineering curriculum materials for grades K-6 and to prepare teachers, who do not generally have a technical background, to implement them. This paper provides an overview of the project and the engineering units that were developed for two 6th grade classrooms. The paper also discusses one engineering unit on roller coasters that was developed and delivered for a 6th grade classroom.

Project Objectives

NSF has a longstanding interest in addressing pipeline issues in technical education. This project represents an opportunity to interest young children, especially girls and underrepresented students, in pursuing technical careers. The goal of the NSF Graduate Teaching Fellows in K-12 Education (GK-12) Program [1] is to prepare engineering graduate students, not necessarily to become K-12 teachers, but to be informed about and engaged in K-12 education throughout their professional careers. Our project is titled "K-6 Gets a Piece of the PIEE (Partnerships Implementing Engineering Education)" [2]; its objectives are to develop a stronger partnership between WPS and WPI; to implement the technology/engineering portion of the Massachusetts Science and Technology/Engineering Curriculum Frameworks (MSTECF) [3] (Massachusetts Curriculum Frameworks, n.d.) in grades K-6; and to develop curricular materials and prepare teachers so that the project self-sustains itself after the NSF grant expires in three years. This partnership is innovative because it is the first to address the Massachusetts Technology/ Engineering Curriculum Frameworks in grades K-6.

Significance

Competition for a limited number of potential engineering majors among institutions of higher education continues to increase, and the future need for scientists and engineers in the U.S. technological workforce far outstrips the anticipated supply. It is becoming increasingly crucial for both academic engineering departments and the U.S. technological workforce that women and minorities, who typically participate and persist in technical fields at much lower rates than white males, are attracted to technical fields in increasing numbers. Typically institutions of higher education attempt to address such "pipeline" issues by interventions targeted at middle and high school students. However, by middle school, students have generally formulated their attitudes toward math and science. Course choices made in middle school, particularly with respect to mathematics, set a student on a virtually irreversible trajectory with respect to preparation for college admission in technical fields. The logical place to intervene is in elementary school, when students' career aspirations are relatively pliable. From a practical standpoint, if one wishes to impact large numbers of minority students, urban public schools are an ideal place for such interventions. From a social responsibility standpoint, many students in urban schools have never entertained the notion that they could go to college, so here is a place where engineering educators can make a meaningful difference.

Worcester Public Schools

Worcester, Massachusetts is the second largest city in the state and third largest city in New England, with a population of over 172,000 people. WPS is an urban system with over 26,000 students and is the second largest school system in the state of Massachusetts. The student body is very diverse and consists of a large numbers of Whites, Hispanics, African Americans and Asians as shown in Figure 1.

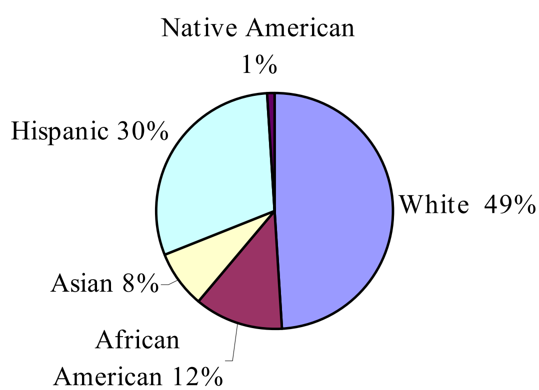

Figure 1. WPS enrollment by ethnicity for 2002-03 academic year [4].

Project Organization

In the three years of the project (2003-2006), we will address grades K-6 in several elementary schools. In the first year (2003-2004), we are working with six classes, one in each of grades 4, 5, and 6 in each of two Worcester elementary schools. A team at each grade level consists of two WPS teachers, two WPI graduate fellows, four undergraduate students and one WPI faculty advisor. Teachers provide grade level pedagogy and curriculum expertise; graduate fellows and undergraduate students provide engineering expertise, ideas, and resources. WPI faculty advisors mentor the graduate and undergraduate students. So that the project will ultimately be self-sustaining, implementation of the curriculum is done primarily by teachers. WPI fellows and undergraduates develop curriculum materials, procure supplies, and support teachers by being present in the classroom to help facilitate the (primarily hands-on) lessons.

In subsequent years, teachers from the first year of the program will mentor colleagues in other schools, and graduate fellow support will be focused on supporting teachers in more schools and developing new curriculum for successively lower grade levels (grades 2 and 3 in 2004-05, and grades K and 1 in 2005-06). After funding expires, teacher mentoring will be sustained by experienced WPS teachers and engineering expertise will be provided by WPI undergraduates.

Personnel

The proposal was written in close collaboration with administrators in the WPS, with whom WPI has a longstanding positive relationship involving multiple collaborations. Once the grant was funded, WPS administrators recruited principals of two elementary schools, who in turn identified interested teachers. The teachers and principals are highly committed to the project. The teachers are compensated as consultants at the rate of $28 per hour for up to 115 hours on the project each year. The 115 hours include a 35-hour summer workshop, and 80 hours (about 2 hours per week) during the school year.

For the first year of the project, seven graduate fellows (three women, one of whom is an underrepresented minority, and four men) were selected from a pool of about 30 applicants. Graduate fellows are expected to devote 30 hours per week to the project during the summer and 20 hours per week during the academic year, including class time, preparation time, and travel time to school. Six graduate fellows are paired with teachers in grade level teams, and one graduate fellow works as an "administrative fellow" to organize meetings, build the project web site, and develop promotional materials. (We anticipate that an administrative fellow position will not be necessary in the second and subsequent years of the project.) Graduate fellows are compensated with full tuition and a $27,500 annual stipend for 2003-04 (in 2004-05 the stipend will be $30,000). Each fellow has a $150 supplies budget and $50 photocopying budget to use for materials in the classrooms in which they are working. We deliberately kept the budget for consumables low because we want to encourage the development of low- or no-cost lessons that will be sustainable by WPS after the grant expires.

During the first year of the project (2003-04), undergraduate students involved in the project are completing a science-technology Interactive Qualifying Project (IQP) that is a WPI degree requirement, and are not compensated. The IQP is equivalent to three WPI courses and is one-quarter of the academic year full-time. For the second and third project years, undergraduates who have worked on the project for one year will be eligible to apply for paid undergraduate fellowships, and we will have additional undergraduate support from new IQP students. Undergraduate students spend 12-15 hr/wk on the project during the academic year, including 2-4 hr/wk in the classroom at the peak of their involvement. After grant funding expires, ongoing teacher support will be provided by IQP students.

WPS Elementary Schools and the 6th Grade Classes

Two WPS elementary schools participated in the project during the 2003-04 school year. Both schools are in the WPS Doherty quadrant on the west side of Worcester. Each school is within a twenty minute walk of WPI. Midland Street School [5] has 230 students in kindergarten through 6th grade. The only 6th grade class at Midland has 33 students. Elm Park Community School [6] has 409 students in preschool through 6th grade. The 6th grade class for this project at Elm Park consists of 21 students. Both schools are culturally and ethnically diverse.

Overview of 6th Grade Engineering Units

The WPS school year schedule is from late August to mid-June. The WPI undergraduate and graduate students were in the classrooms from early September to mid-May. Appendices A and B contain an overview of the 6th grade units and corresponding lessons that were developed for Midland Street and Elm Park Community Schools, respectively, during the 2003-04 school year. The tables in Appendices A and B show the unit, lessons associated with each unit, lesson objectives and applicable Massachusetts Curriculum Frameworks for each lesson. The units in Appendices A and B that can be used by a teacher in his/her classroom can be obtained from the PIEE web site at http://www.wpi.edu/Academics/PIEE/ or by contacting either Joseph J. Rencis (jjrencis@wpi.edu) or Judith E. Miller (jmiller@wpi.edu). Engineering units were developed based on the Massachusetts Science and Technology/Engineering Curriculum Frameworks [3]. The Frameworks were created by the Massachusetts Department of Education in 2001.

Roller Coaster Unit

Overview

Children become engaged in an activity when they can see, touch, manipulate and modify things [7]. The lessons developed for this unit used that hands-on approach. The goal of the unit is to first provide an understanding of roller coaster physics and then apply the engineering design process to design, build and test a roller coaster. Since most children have ridden or at least seen a roller coaster, these experiences formed the foundation which this unit was developed. This unit was naturally integrated into the science curriculum since the science book explores roller coaster physics.

The first lesson introduced common physics vocabulary and used in-class demonstrations to reinforce the concepts. The second lesson applied this knowledge in experimenting with a virtual roller coaster. In lesson three the students coupled this knowledge with the engineering design process to design, build and test a virtual roller coaster. The fourth and final lesson used these engineering skills to solve an in-class, hands-on activity using a simplified roller coaster model. Appendix C contains the roller coaster unit that was presented in the 6th grade class at the Midland Street School. The material in this appendix can be used by a teacher in his/her classroom.

Lessons and Implementation

The roller coaster unit was divided into four lessons and each lesson was completed on a separate school day. An overview of the unit is shown in Table 1 and required fours hours of classroom time to complete.

Table 1. Overview of lessons in roller coaster unit.

	Lesson Number			
	1	2	3	4
Topic	Physics: Forces and Energy	Roller Coaster Fundamentals	Design, Build, Test and Redesign a Virtual Roller Coaster	Application of Engineering to Actual Roller Coasters
Format	Lecture and Demonstrations	Lecture and Web Experiment	Web Design	Hands-On Activity
	Whole Class	Whole Class	Small Groups	Small Groups
Objective	To define and demonstrate forces and energy.	To explain and apply knowledge of forces and energy to virtual roller coasters.	To design, build, test, and redesign a virtual roller coaster.	To apply knowledge of forces and energy to an actual roller coaster.
Classroom Time	1 Hour	1 Hour	1 Hour	1 Hour
Massachusetts Curriculum Frameworks [3]	Strand 3: Standard 13 and Strand 4: Standard 6.4	Strand 3: Standard 11 and Strand 4: Standards 6.2 & 6.3	Strand 3: Standard 11 and Strand 4: Standards 6.2 & 6.3	Strand 4: Standards 6.3 & 6.4

The first lesson introduced forces and energy through two activities with each activity requiring thirty minutes of class time. The first activity presented force through a hands-on approach. The concepts of force and friction are first discussed using the science book [8]. An in-class demonstration involved applying a horizontal force to the book and then asking the class to determine why the book stopped moving when the force was removed. The second activity covered the basics of energy and required thirty minutes to complete. Energy was first discussed using the science book. An in-class demonstration was then used to identify how potential and kinetic energy change when a pencil is dropped. Having introduced these fundamental concepts, the students were now prepared to apply this knowledge to a real-world device, e.g., car, train, roller coaster, etc.

The second lesson applied force and energy to roller coasters and required one hour of class time to implement. The science book was used to apply what was learned about forces and energy to roller coasters. A photo of a roller coaster from the textbook showed the relative magnitudes of the forces and energy at different locations on the roller coaster track. The first web site in Figure 2 allowed the students to experiment with such roller coaster characteristics as hill height, loop size, initial cart speed, cart mass, gravity and track friction. Students could then test and observe the resulting changes in cart motion visually on the screen. Values for cart speed and time are also shown on the web site.

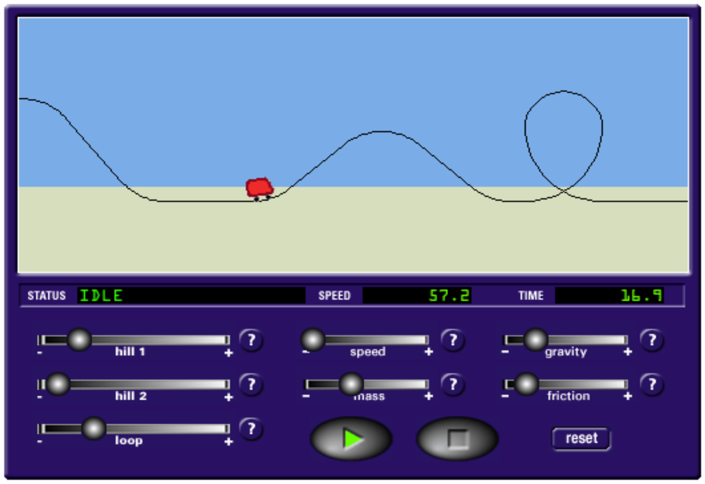

Figure 2. Web site to experiment with a virtual roller coaster [9].

Lesson three used a second website shown in Figure 3 that applied the students' understanding of roller coaster physics developed in the second lesson. This second interactive web site allowed the student to design, build, test and redesign a virtual roller coaster. The engineering design process in the Massachusetts Technology/Engineering Curriculum Frameworks [3] was integrated into this lesson since the second website provided an assessment of the safety and fun of the roller coaster design. The students can then use this feedback to redesign their roller coaster.

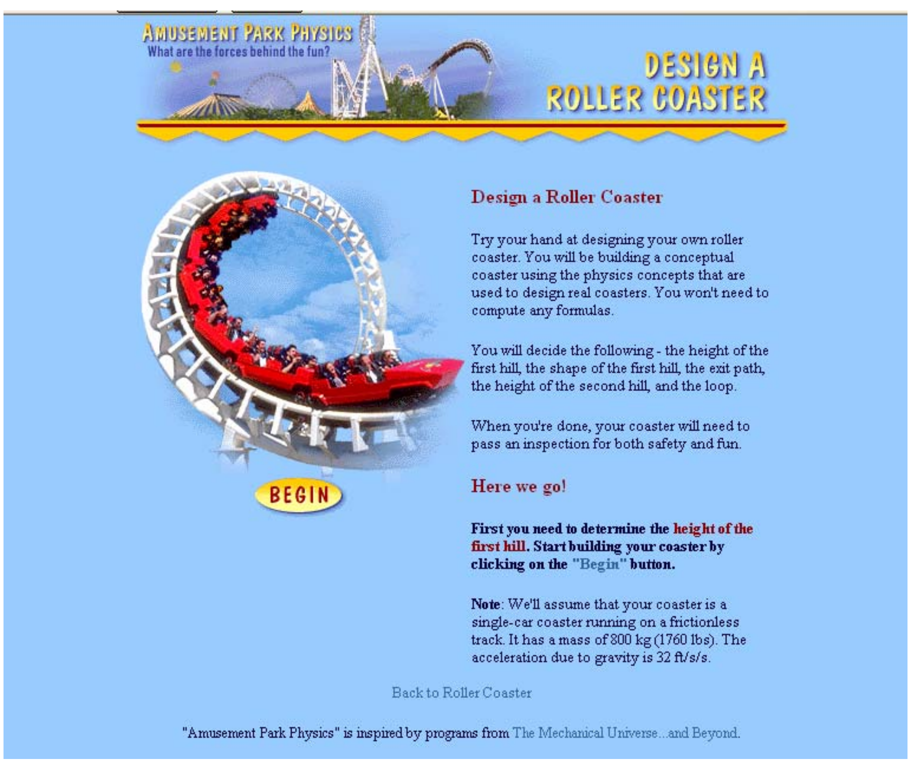

Figure 3. Web site to design, build, test and evaluate a virtual roller coaster [10].

The fourth lesson applied the knowledge from the three previous lessons to a simplified roller coaster model. This lesson can be completed in a one-hour time period. The simplified roller coaster model has two components: a wooden ramp is used for the track and round objects (ball bearings, pencils, pens and toy cars) to represent a cart. The hill height can be adjusted so that the student can observe the correlation between the track angle and cart speed. The time it took for a cart to roll down the track was measured, recorded and graphed. A group of students carrying out the experiment is shown in Figure 4. Conclusions were drawn as to which cart type rolled the fastest. A brainstorming session was used to determine how to make each cart roll faster. Changes in hill height, track surface type and cart type were tabulated. The students were required to analyze and discussed the data in a project report.

Figure 4. Students working with simplified roller coaster model in the classroom.

Assessment

The unit was assessed in two parts that included the overall unit and student work. The teacher used the rubric in Table 2 to assess the overall unit after the four lessons had been implemented.

Table 2. Rubric used to for roller coaster unit to evaluate the overall unit.

Unit Components	Scale				Points
	1	2	3	4	
The unit encouraged original ideas from the students.	None of the Time	Some of the Time	Most of the Time	All of the Time	
The unit was appropriate for the grade level.	None of the Time	Some of the Time	Most of the Time	All of the Time	
The unit taught students about engineering.	None of the Time	Some of the Time	Most of the Time	All of the Time	
The unit contained useful lessons.	None of the Time	Some of the Time	Most of the Time	All of the Time	
				Total	

The teacher used the rubric in Table 3 to assess student work through the vocabulary worksheet, the table and graph worksheet and the project report worksheet. The worksheets can be found in Appendix C.

Table 3. Rubric used for roller coaster unit to evaluate student work through worksheets.

Worksheet	Scale				Points
	1	2	3	4	
	Demonstrates No Understanding	**Demonstrates Little Understanding**	**Demonstrates Some Understanding**	**Demonstrates Thorough Understanding**	
Vocabulary	Less Than 4 Definitions Correct	4 or 5 Definitions Correct	6 or 7 Definitions Correct	8 Definitions Correct	
Table and Graph	Table incomplete or incorrect Graph sloppy and plot does not represent the table.	Table complete, but data incorrect. Graph sloppy, but is close to matching the data in the table.	Table completely filled. Graph drawn carefully, though not completely correct, close.	Table completely filled in. Graph carefully and properly drawn using the data in the table.	
Project Report	Unclear explanations, though main concepts were missed. Ideas show lack of thought, unoriginal or a copy of class work.	Some work was done. Some ideas formulated, though explained in an abstruse fashion.	Thoughtful explanations, though not completely clear. Original ideas.	Clear, thoughtful explanations. Ingenuity of ideas.	
				Total	

The vocabulary worksheet evaluated the students' knowledge of roller coaster physics. This homework assignment was given out after the first lesson and the students were given one day to complete it. Using the table and graph worksheet, the students recorded their data and drew a graph based on the roller coaster model in lesson four. The second homework assignment required the students to brainstorm in class and discuss possible improvements to the simple roller coaster model activity using the project report worksheet. Once all the worksheets were collected, the teachers evaluated the work according to the rubric in Table 3. Teacher feedback on the overall unit and student work can be used to determine the level of understanding and possible modifications to the unit.

Conclusion

The introduction of engineering into an elementary school classroom has been a large effort for all individuals involved in this project. The challenges have been to find the time to introduce engineering into the curriculum and method to present engineering concepts to WPS teachers and students. Both challenges have been meet by integrating engineering into the existing science curriculum.

Teachers and WPI students have reported a high level of excitement and increased interest in engineering across both genders and ethnicities. Excitement continues to grow among WPS teachers and students, providing more opportunities for projects and activities in the future.

Keys to Success

A key element of the success of this project is the true partnership between WPS and WPI. Public school personnel, understandably, approach collaborations with higher education cautiously, anticipating that the university "partner" will dominate the relationship and have little appreciation of or respect for the school culture. At the same time, higher education often faults K-12 for not understanding higher education's culture and always expecting "handouts." The PIEE project has drawn consistent praise from WPS personnel, due primarily to their perception that WPI team members approach the project with respect for the expertise and authority of the teachers, and with sensitivity to the culture and constraints of the public schools. By focusing on supporting the schools' needs, sharing our expertise rather than imposing our own agenda, and by learning about and cultivating the young students who may be our future clientele, we appear to be well on the way to developing a partnership that will benefit all of the players.

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Appendix A. Overview of Engineering Units for Midland School 6th Grade

Table A.1 Overview of Engineering Units for Midland School 6th Grade

Unit	Lesson Title	Objectives	Massachusetts Frameworks
Introduction to Engineering	What do engineers do?	To get students thinking about the jobs that engineers have.	N/A
	What is the engineering design process?	To introduce students to the engineering design process.	Identify and explain the steps of the engineering design process.
Animal Habitats – Where will I live?	Animal Research	To teach students ways to research a problem (Design process).	Identify and explain a step of the engineering design process.
	Habitat Design	To teach students the importance of developing a planned design (DP).	Identify and explain a step of the engineering design process.
	Habitat Building	To show students the benefits of constructing a prototype (DP).	Identify appropriate materials and tools to construct a prototype.
	Habitat Presentation	To give students an opportunity to present their habitat and what they've learned to the rest of the class (DP).	Demonstrate methods of representing a solution to a problem.
The Human Body	What are the major functions of the human body?	To give background information on the human body explaining tissues, organs, and systems.	Describe the organization of multicellular organisms.
	Research a given body system in groups.	To get students to research a given body system and learn about its function and necessity.	Identify functions of the major systems of the human body.
	Develop a body system lab report.	To develop students skill in presenting what they have learned in a lab report format.	Demonstrate methods of representing a solution to a problem.
	What is biomedical engineering?	To introduce students to biomedical engineering and relate it to the major body systems.	Explain examples of adaptive and assistive devices and bioengineered products.

Unit	Lesson Title	Objectives	Massachusetts Frameworks
NSIP (NASA Student Involvement Program)	Research NASA, NSIP, thrust structures, and the X-33	To get students to develop a good background knowledge for a long-term engineering design project.	Identify and explain the steps of the engineering design process.
	Thrust Structure Design	To let students develop an initial design and to teach them to properly sketch and describe it.	Identify and explain a step of the engineering design process.
	Thrust Structure Building	To give students an opportunity to bring their design from sketch to prototype.	Identify and explain a step of the engineering design process.
	Thrust Structure Redesign (as many times as necessary)	To show the students the importance of redesign and give them the opportunity to apply this concept to their thrust structure project.	Identify functions of the major systems of the human body.
	Design storyboard and summary report	To develop the importance to presenting a design to others and also to advance students writing skills.	Demonstrate methods of representing a solution to a problem.
Roller coasters – How do they work?	What are forces and what are potential and kinetic energy?	To introduce students to the fundamental physics of transportation.	Explain kinetic and potential energy, friction, and gravity.
	How do you design a roller coaster?	To get students to apply the science concepts and the engineering design process to design a roller coaster.	Identify and explain a step of the engineering design process.
	A qualitative analysis of roller coaster physics.	To get students to think about improving a ramp design using fundamental physics concepts.	Explain the motion of an object and develop a transportation problem solution.

Unit	Lesson Title	Objectives	Massachusetts Frameworks
Bridges	What's so special about the shape of a bridge?	To get the students to think about how the structure of a bridge affects its strength and stability.	Identify and describe three major types of bridges.
	How can I design a low-cost reliable bridge?	To allow students to apply their knowledge to design a bridge meeting given specifications.	Explain parts of a structure, forces, and effects of loads.
	Build-a-bridge	To give students more practice in bringing their design from page to prototype.	Identify and explain a step of the engineering design process.
	Bridge testing and wrap-up	To see how well the student's bridge designs hold up and to get them thinking about how they might improve their designs.	Identify and explain a step of the engineering design process.
Space Day	An engineering type lesson will be designed for annual space day activities		
Communications and Manufacturing	Some stand-alone engineering lessons	To close out the school year in other areas covered by the Massachusetts Curriculum Frameworks.	

Appendix B. Overview of Engineering Units for Elm Park Community School 6th Grade

Table A.1. Overview of Engineering Units for Elm Park Community School 6th Grade.

Unit	Lesson Title	Objectives	Massachusetts Frameworks
Introduction to Engineering	Engineering Display Board	Learn about Engineering, the Engineering Design Process.	Identify the steps of the engineering design process.
	Who are Engineers?	Correct misconceptions of what students think engineers do.	Identify the steps of the engineering design process.
Writing	Creating a New Ending to a Story	Learn to be more creative.	Developing possible solutions.
Brainstorming	Introduction to Brainstorming	Learn how to brainstorm correctly and learning the rules of brainstorming.	Develop possible solutions to a problem.
	Brainstorming Engineering Problems	Apply brainstorming to real world problems.	Develop possible solutions to a problem.
	Brainstorming Solutions Using the Matrix	Apply knowledge of the Matrix.	Selecting the best possible solution.
	Inventions Idea Survey	Brainstorm possible ideas for inventions.	Develop possible solutions to a problem.
	Making the School Better	Brainstorm how to make the school better.	Develop possible solutions to a problem.
Engineering Design Process	Using the Matrix	Use the Matrix to solve problems.	Selecting the best possible solution.
	Problem Statement and Steps for Implementation	Learn to describe a problem and steps to solve the problem.	Communicate a solution.
	Projects Fair	Brainstorm ideas for the projects fair.	Engineering Design Process.
Tools	Tool of the Month: Drill Press	Learn about the drill press and how it works.	Identify and explain appropriate tools.
	Tool of the Month: Band Saw	Learn about the band saw and how it works.	Identify and explain appropriate tools.
	Tool of the Month: Clamps	Learn about clamps and how they work.	Identify and explain appropriate tools.
	Tool of the Month: Tools that Lift	Learn about tools that lift (levers, gears, hydraulics).	Identify and explain appropriate tools.
	Machine Tools	Learn about machine tools and how they relate to basic tools.	Identify and explain appropriate tools.
	Tool of the Month: Tools that Measure	Learn about tools that measure.	Identify and explain appropriate tools.
	Tool of the Month: Hammers	Learn about the different types of hammers and their purpose.	Identify and explain appropriate tools.

Unit	Lesson Title	Objectives	Massachusetts Frameworks
Tools	Tool of the Month: Screwdriver & Wrench	Learn about tools that tighten.	Identify and explain appropriate tools.
	Tool of the Month: Tools that Separate	Learn about different tools used to separate.	Identify and explain appropriate tools.
Transportation	Creating a Wind Powered Vehicle	Understanding wind power.	Identify a transportation system.
	Brainstorming lesson on Transportation	Learn about possible transportation in a city.	Identify transportation devices.
	Worcester Subway	Understand subways and learn about their city.	Explain possible solution to a transportation problem.
	Airplane Design	Learn how airplanes work and the forces that act on them.	Identify subsystems of a transportation vehicle.
Research	Internet Research Lab	Learn how to research and learn more about their city.	Research the problem.
Inventions	Thomas Edison & Inventions	Learn about Thomas Edison and his inventions.	Research
Communications	Brainstorming on communications	Learn about different ways to communicate.	Develop possible solutions.
	Communication Components & Devices	Learn about the different components in a communications device.	Explain components of a communications.
	Communicating without Words	Learn how people communicate without words.	Develop possible solutions to a problem.
Bioengineering	Helping the Disabled	Learn about disabilities and brainstorm ways to help them.	Explain examples of assistive devices.
Materials	Weight, Hardness, and Flexibility	Understand a materials weight, hardness, flexibility, and how to find it.	Identify appropriate materials and properties.
Manufacturing	Creating a New Product	Learn about manufacturing and products.	Explain basic processes in manufacturing systems.
Construction	Buildings	Understand components of a building.	Explain parts of a structure.
	Building a tower	Use creativity to build the tallest paper tower.	Describe parts of a structure.
	Introduction to Bridges and Forces	Learn about bridge basics.	Describe three major types of bridges.
	Bridges and Forces	Understand the forces that act on a bridge.	Explain the forces of tension, compression, and bending.

Appendix C. Roller Coaster Unit

The following items are contained in this appendix:

- Unit Plan – Pages 17 and 18
- Lesson Descriptions – Pages 19 and 20
- Vocabulary Worksheet – Page 21
- Table and Graph Worksheet – Page 22
- Project Report Worksheet – Page 23
- Rubric for Unit – Page 24
- Rubric for Student Worksheets – Page 25
- Bulletin Board Display – Pages 26 - 29

Unit Title: Roller Coasters - How They Work

Name: Kevin Fichter, Crystal Bishop

Grade: 6

Discipline: Science/Engineering

Purpose: To teach the students about the forces and energy involved in a roller coaster. They will also learn some engineering principles, such as how to design and test a simple prototype of a roller coaster.

Objectives:
- To understand the fundamental physics of transportation.
- To apply the engineering design process.
- Give students an opportunity to build a design prototype.

Student Outcomes:
Students will design and build a simple roller coaster, and understand the dynamics of roller coasters at various locations on a track. They will also discover some methods used to overcome friction.

Essential Question: How does a roller coaster work?

Lesson	Standard
Lesson Question 1a What are forces? **Lesson Question 1b** What is energy? Forces and energy are defined and demonstrated.	**Standard Addressed** Strand 3 Standard 13 & Strand 4 Standard 6.4 & WPS Benchmarks: Mass & Gravity **Length of Lesson** 1 Hour **Instructional Mode:** Whole Class
Lesson Question 2 How does a roller coaster work? Roller coasters are explained, and tied in with lesson 1.	**Standard Addressed** Strand 3 Standard 11, Strand 4 Standards 6.2 and 6.3 **Length of Lesson** 1 Hour **Instructional Mode:** Whole Class
Lesson Question 3 Why is the design of a roller coaster important to its function? A virtual roller coaster will be built and then redesigned by the students.	**Standard Addressed** Strand 3 Standard 11, Strand 4 Standards 6.2 and 6.3 **Length of Lesson** 1 Hour **Instructional Mode:** Small Group
Lesson Question 4 How do different aspects of a roller coaster affect the timing of the ride? Students will use adjustable ramps and ball bearings, adjusting the ramp to find when the bearing rolls down the ramp the fastest.	**Standard Addressed** Strand 4 Standards 6.3 and 6.4 **Length of Lesson** 1 Hour **Instructional Mode:** Small Group

Tools and Resources:
- Round Objects: 1 ball bearing, pencil, pen or toy car for each group of 3 - 4 students.
- Textbooks
- Ramps: 1 per group of 3 - 4 students.
- Computers with Internet Access (1 per group preferable)

References:

1. Addison-Wesley Destinations in Science, Addison-Wesley Publishing Company, Inc., Reading, MA, ©1995 pages 10-11, 30, 52-53.
2. "Funderstanding Roller coaster," Funderstanding.com Inc., Livingston, NJ, http://www.Funderstanding.com/k12/coaster/ (retrieved 1/31/04).
3. "Amusement Park Physics," Annenberg/CPB, Washington, DC, http://www.learner.org/exhibits/parkphysics/coaster/section1.html (retrieved 1/31/04).

Assessment:
Student work will be assessed through the vocabulary worksheet, the table and graph worksheet and the project report worksheet.

Credits:
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Lesson Descriptions

Lesson 1a – What Are Forces?

- Explain forces. "A force is something that causes an object to move in a direction."
- Demonstration 1: Have a student come to the front of the class, and move a book across a desk. The student is applying a force on the book.
- Gravity is a force; it is the 'something' that causes you to come down when you jump in the air. Without it, you would float around as if you were an astronaut in space.
- Friction is the force that causes a moving object to stop. Have students read the definition on pages D10-D11 of Destinations in Science [1]. Explain that the reason the book stops when it is pushed is because of friction.
- Centripetal force: when you are in a car, and it takes a sharp turn, you are pushed against the door, there is a force causing that, it is centripetal force.
  Have a student read the definition on page D30 of Destinations in Science.

Lesson 1b – What Is Energy?

- *Energy*: Say "Energy is the ability to do work. Work is done when an object moves. Work was being done when the book moved, so it had energy."
- *Potential Energy and Potential Energy*: Demonstration 2: Have the students pick up their pencils, and hold them over the aisle. Say "The pencil now has potential energy, because it is not moving. Potential energy is energy that is stored, and then later used. The higher you hold the pencil, the more potential energy it will have."
- Have the students drop the pencils. Say "The potential energy of the pencils turned into kinetic energy when you let go, and they fell. Kinetic energy is energy that is being used."
- *Work*: Explain: "You were doing work when you lifted the pencil into the air, and giving it potential energy. Gravity did the work when you dropped the pencil, converting the potential energy into kinetic energy. When the pencil landed, friction stopped it from rolling around forever."
- Assign the first homework sheet at the end of the lesson.

Lesson 2 - How Does a Roller Coaster Work?

- Have the students open to page D52, and have a student read the page aloud.
- Draw a similar picture of a roller coaster as found on page D52 on the board. Pick a student to identify one of the 5 points as in the book, and have a student read the description from the book. Repeat this step for all 5 points.
- Comment to the students the structure supporting the track, tell them that the white pole-like structures are supporting the weight of the track, and the weight of the people as they go around the track.
- Explain that the main propulsion of a roller coaster is gravity. However, for some hills, and when the ride first starts, the car is propelled using machines under the track and car.

- Explain to the students what determines where the car goes on the track. The track acts as guidance for the car, forcing the car to go wherever the track goes, just like a train and train tracks.

Lesson 3 – Simulating a Roller Coaster

- Have the children split into small groups for use on computers
- Have the students play with the simulated roller coaster at http://www.Funderstanding.com/k12/coaster/ for about 15 minutes. The students can modify the roller coaster and test the results of their changes. They can modify gravity, the height of the hills, the size of the loops, initial speed, mass and the friction on the track.
- Have the child take note to the changes of the speed and time of their ride after they change something.
- After the 15 minutes have passed, the students should have an idea of how a roller coaster works, and the various forces and aspects which affect a roller coaster's performance.
- Have the students navigate their browsers to http://www.learner.org/exhibits/parkphysics/coaster/section1.html. This site will test their understanding of what they just learned in a simulation where they get to design and build a simulated roller coaster.
- Ask the students to design a roller coaster on this site, using what they learned from the first interactive site.
- After designing, the students should carefully read the safety inspection provided by the website.
- A redesign maybe necessary and should be completed in their engineering journals along with explanations for why the changes to the design are necessary.

Lesson 4 – How Do You Build A Basic Roller Coaster?

- Split the students into groups of about 4, and have each group collect a ramp and a ball or round pencil (not hexagonal) or any uniformly cylindrical object.
- Have the groups measure the length of the ramps, then have them set up the ramps, and have them measure how high the high end of the ramp is off of the table. Have the students record this data on the included data sheet.
- Next, have the groups roll a pencil or whichever cylindrical object they chose down the ramp. Have the students record the time it took for the pencil or object to roll from the top of the ramp to the bottom.
- Have the groups adjust the height of the ramp, and redo the last step.
- Repeat the last two steps once more, for a total of three trials.
- Have the students graph the data on the datasheet. If the students do not finish this during the class period, it can be done as homework.
- Assign the second attached homework sheet.

Vocabulary Worksheet

Name: ____________________________ Date: ____________________________

Write in the definition for each of the following terms:

Forces -

Gravity -

Centripetal Force -

Friction -

Energy -

Work -

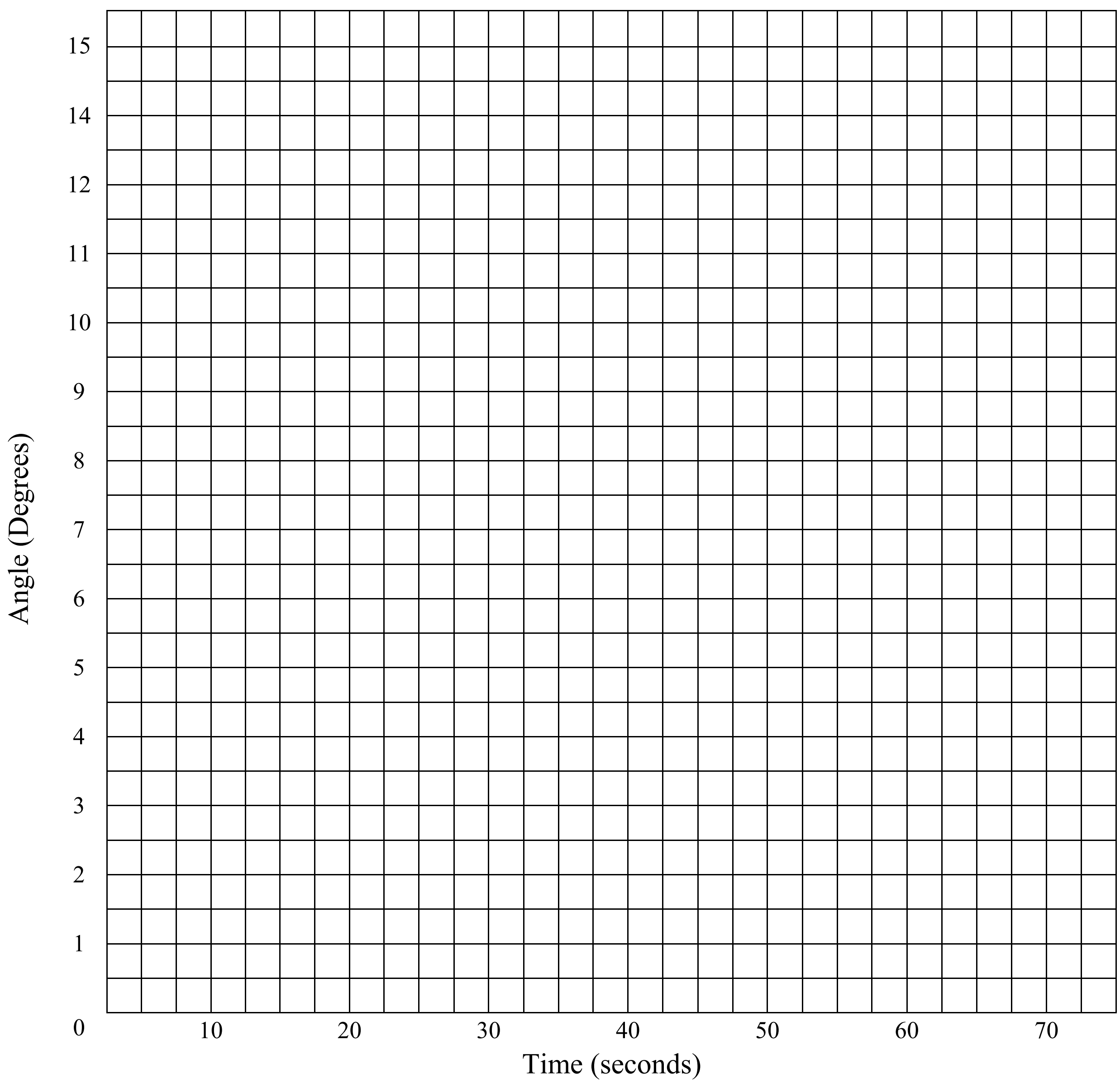
Kinetic Energy -

Potential Energy -

Table and Graph Worksheet

Name: ____________________________ Date: ____________________________

	Trial #1	Trial #2	Trial #3
Ramp Length (inches)			
Time Object Took to Roll Down Ramp (seconds)			
Ramp Angle (degrees)			



Project Report Worksheet

Name: ____________________________ Date: ____________________________

Look over the data that you recorded in class today. Brainstorm a few ideas on how your group could have made the ball go even faster.

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Are there any items that could have helped? Make a list of some items in the classroom or that you found around your house.

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Explain how you would redesign the ramp with these items. Also explain why they would make the ball go faster.

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Rubric to evaluate unit.

Unit Components	Scale				Points
	1	2	3	4	
The unit encouraged original ideas from the students.	None of the Time	Some of the Time	Most of the Time	All of the Time	
The unit was appropriate for the grade level.	None of the Time	Some of the Time	Most of the Time	All of the Time	
The unit taught students about engineering.	None of the Time	Some of the Time	Most of the Time	All of the Time	
The unit contained useful lessons.	None of the Time	Some of the Time	Most of the Time	All of the Time	
				Total	

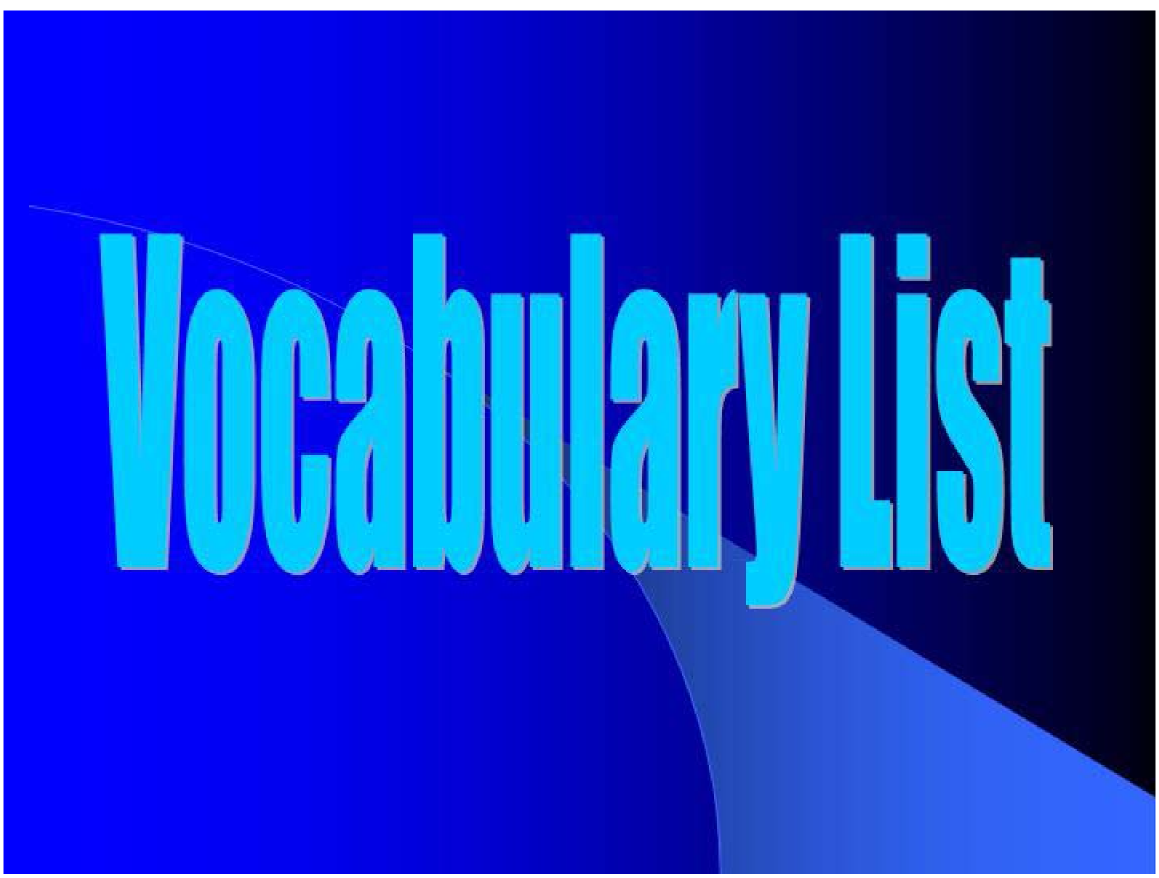
Name: ____________________________ Date: ____________________________

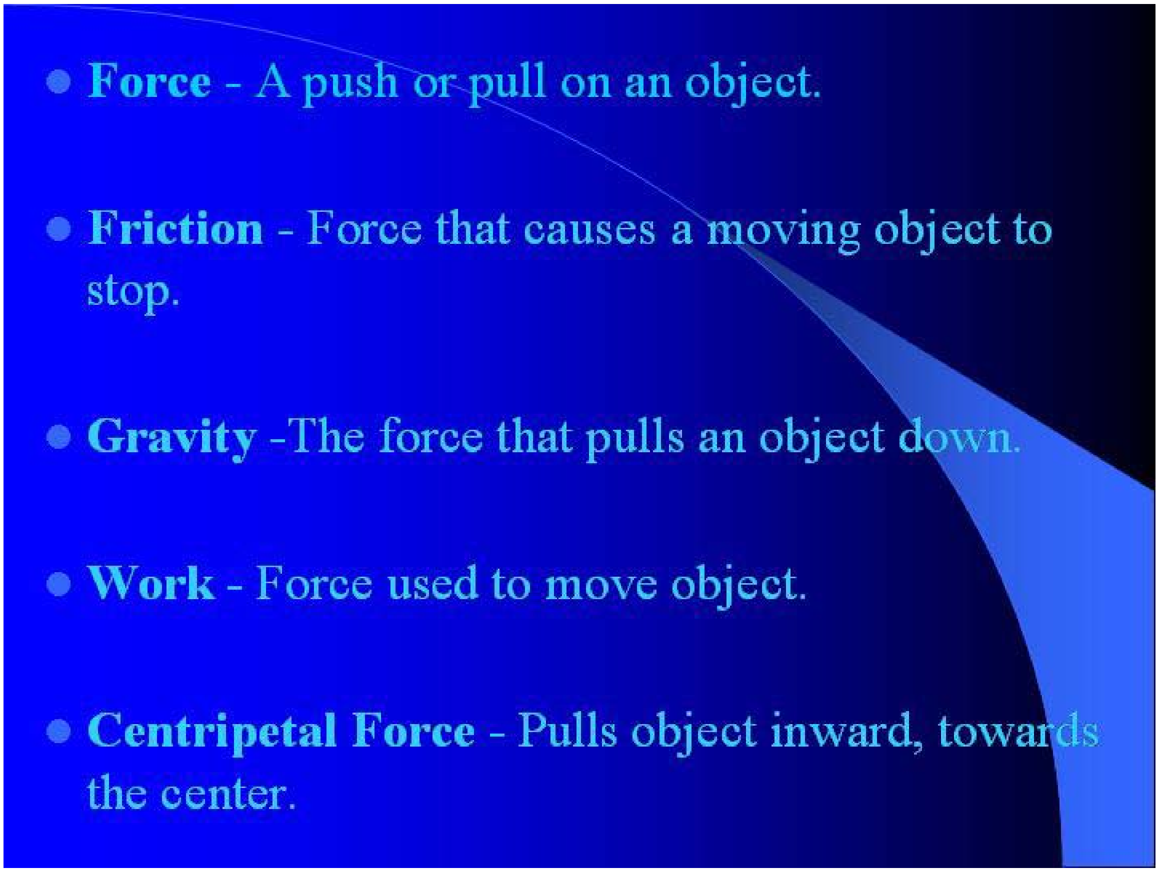
Rubric to evaluate student work through worksheets.

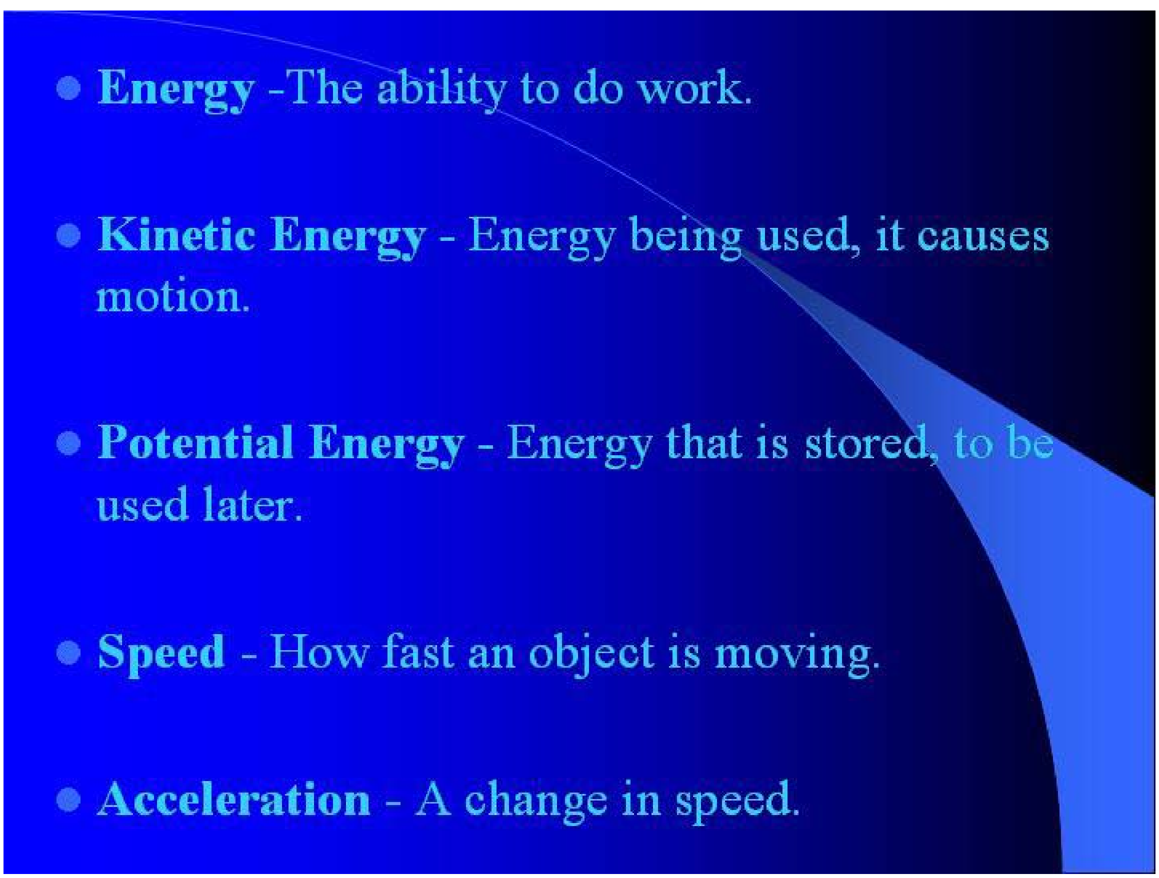
Worksheet	**Scale**				**Points**
	1	**2**	**3**	**4**	
	Demonstrates No Understanding	**Demonstrates Little Understanding**	**Demonstrates Some Understanding**	**Demonstrates Thorough Understanding**	
Vocabulary	Less Than 4 Definitions Correct	4 or 5 Definitions Correct	6 or 7 Definitions Correct	8 Definitions Correct	
Table and Graph	Table incomplete or incorrect Graph sloppy and plot does not represent the table.	Table complete, but data incorrect. Graph sloppy, but is close to matching the data in the table.	Table completely filled. Graph drawn carefully, though not completely correct, close.	Table completely filled in. Graph carefully and properly drawn using the data in the table.	
Project Report	Unclear explanations, though main concepts were missed. Ideas show lack of thought, unoriginal or a copy of class work.	Some work was done. Some ideas formulated, though explained in an abstruse fashion.	Thoughtful explanations, though not completely clear. Original ideas.	Clear, thoughtful explanations. Ingenuity of ideas.	
				Total	

Comments:


Rollercoasters


Vocabulary List


Force - A push or pull on an object.
Friction - Force that causes a moving object to stop.
Gravity -The force that pulls an object down.
Work - Force used to move object.
Centripetal Force - Pulls object inward, towards the center.


Energy -The ability to do work.
Kinetic Energy - Energy being used, it causes motion.
Potential Energy - Energy that is stored, to be used later.
Speed - How fast an object is moving.
Acceleration - A change in speed.

How do they move?

- Rollercoasters do not have engines, so how do they move?
  - A rollercoaster ride is made possible by forces.
  - The force of gravity helps move the rollercoaster over the track.
  - The kinetic and potential energy of the rollercoaster are constantly changing throughout the track.
  - Over time the ride loses some energy because of friction, until it finally reaches a stop.

What are the changing forces?

- During a rollercoaster ride there are many changing forces, what are they?
  - The rides starts off with a steep incline, this builds up potential energy.
  - The remaining hills, loops, and turns help to change the energy back and forth, to potential and kinetic.
  - These changes result in a change in speed, acceleration, of the rollercoaster.

Hill

- The first hill gives the amount of potential energy for the rest of the ride.
- Other hills in the track effect the speed of the ride

Loop

- The size of a loop determines the speed needed to safely complete it.
- The size also will determine the amount of force from gravity the riders feel while travel through the loop.