The Great Roller Coaster Design Challenge
Cheri Nations, North Gwinnett Middle School

Unit Overview
In this project-based learning unit that integrates engineering, physical science, and visual arts, students assume the role of an engineer to build a safe, stable, and fun roller coaster. Using the Engineering Design Process, students research effective designs, sketch a prototype, build the roller coaster, and calculate its energy and average speed of the roller coaster. Throughout the unit, students document the design process and use the pictures and video to create an online presentation for their peers. Students finish the unit by grading their peers' work.

Standards Addressed
1. **S8CS1:** Students will explore the importance of curiosity, honesty, openness and skepticism in science and will exhibit these traits in their own efforts to understand how the world works.
   a. Understand the importance of—and keep—honest, clear, and accurate records in science.
   b. Understand that hypotheses can be valuable even if they turn out not to be completely accurate.

2. **S8CS3:** Students will have the computation and estimation skills necessary for analyzing data and following scientific explanations
   a. Analyze scientific data by using, interpreting, and comparing numbers in several equivalent forms, such as integers, fractions, decimals, and percents.
   b. Find the mean, median, and mode and use them to analyze a set of scientific data.
   c. Apply the metric system to scientific investigations that include metric to metric conversions (i.e., centimeters to meters).

3. **S8CS4:** Students will use tools and instruments for observing, measuring, and manipulating equipment and materials in scientific activities utilizing safe laboratory procedures.
   b. Use appropriate tools and units for measuring objects and/or substances.

4. **S8CS5:** Students will use the ideas of system, model, change, and scale in exploring scientific and technological matters.
   a. Observe and explain how parts can be related to other parts in a system such as the role of simple machines in complex machines.
   b. Understand that different models (such as physical replicas, pictures, and analogies) can be used to represent the same thing.

5. **S8CS6:** Students will communicate scientific ideas and activities clearly.

c. Organize scientific information in appropriate tables, charts, and graphs, and identify relationships they reveal.

6. **S8CS10:** Students will enhance reading in all curriculum areas by:
   c. Building vocabulary knowledge
   - Demonstrate an understanding of contextual vocabulary in various subjects.
   - Use content vocabulary in writing and speaking.
   - Explore understanding of new words found in subject area texts.

7. **S8P2:** Students will be familiar with the forms and transformations of energy.
   a. Explain energy transformation in terms of the Law of Conservation of Energy.
   b. Explain the relationship between potential and kinetic energy.
   c. Compare and contrast the different forms of energy (heat, light, electricity, mechanical motion, sound) and their characteristics.

8. **S8P3:** Students will investigate relationship between force, mass, and the motion of objects.
   a. Determine the relationship between velocity and acceleration.
   b. Demonstrate the effect of balanced and unbalanced forces on an object in terms of gravity, inertia, and friction.
   c. Demonstrate the effect of simple machines (lever, inclined plane, pulley, wedge, screw, and wheel and axle) on work.

9. **STEM-EA-4:** Apply knowledge of the engineering design process to solve engineering/ technological problems in the STEM workplace.
   a. Identify, define, and research a technological problem.
   b. Utilize planning, time management, and leadership skills to organize an engineering project.
   c. Research, select, and safely apply engineering concepts, machines, and tools for completion of the project.
   d. Develop alternative solutions to a technological problem.
   e. Select an appropriate solution that optimizes the outcome based on the specifications, constraints, and resources of the project

10. **STEM-EA-9:** Design and construct a testable prototype.
    a. Understand the concept of prototype as it relates to engineering design.
    b. Select and apply appropriate materials, tools, and processes for prototype development.
    c. Consider end user experience and interface in prototype development.
    d. Test prototype for performance, usability, and durability.
    e. Assess and evaluate prototype testing data to recommend design improvements, optimization, or re-design of prototype.

11. **STEM-EA-10:** Understand engineering impacts of social, economic, design and environmental issues.
    a. Apply knowledge of external issues such as time constraints, budget, supply chain and available technology that strain the engineering design process to optimize a solution to a STEM problem.

12. **VA8MC.1:** Engages in the creative process to generate and visualize ideas.
    a. Uses elements of art and principles of design to expand imagination and develop meaningful ideas.
    b. Visualizes unique ideas and formulates artistic concepts to expand the imagination using a variety of approaches (e.g., mental and visual imagery, brainstorming lists, visual journals, sketches, art resource collections, discussions

13. **VA8MC.2:** Identifies and works to solves problems through authentic engagement (thinking, planning, and experimenting) with art methods and materials, exploring the nature of creativity.
    b. Employs multiple problem-solving strategies to develop a variety of solutions to artistic problem; evaluating the merits of each.
    c. Engages in open-ended inquiry and solves artistic problems through discussion and respectful interaction with peers.

Day 1 – Identifying the Problem

Standards Addressed: 1, 9, 11

Essential Question: What is the problem?

1. Begin the lesson by reviewing the Engineering Design Process (EDP) with students. Students should be familiar with the EDP from their content science classes.

2. Introduce the problem by providing students with a story which illustrates why roller coasters should be both fun and safe. For example, you may consider telling students that you do not allow your children to ride roller coasters because you cannot ensure their safety. Explain that, for this project, students will be roller coaster engineers who will use the EDP to design and build a roller coaster that will be thrilling and safe for riders.

3. Ask the students to independently visualize the last time they were on a roller coaster. After a moment of thinking, give students three to four minutes to jot down responses to the following questions in

A Note from the Teacher

This unit plan was written for a physical science enrichment course. I expect for students to know the physical science standards before beginning the project. To ensure that all students are beginning with the same content knowledge, I give a diagnostic test to gauge how much physical science content I need to review the before introducing the project. For teachers wanting to use the plan for their general physical science class, make sure to dive deeper into the physical science concepts.

their science journals: Did you like it or hate it? Was it fast or slow? Did it have steep hills? Did you like the buildup as you climbed the first hill and the exhilaration as you went down? Were there loops or just hills? Were there a lot of changes in direction? Did you want to ride it again when it was finished? Was it metal or wood? Were you strapped in well enough to feel secure?

4. Once students have written down their thoughts, ask for volunteers to share their thoughts about the last roller coaster they rode.

5. Give students about ten minutes to brainstorm with their group the information they would need to design a roller coaster. Tell students to consider anything they need more information about, components they would like to include, and criteria or constraints of the problem. Make sure to circulate the room and conference with the groups. Make suggestions to the groups about the information they may need before beginning to design their roller coaster.

6. Draw three columns on the board and label them Components, Constraints/Criteria, and Safety. When the class is finished brainstorming, ask for groups to share out what they came up with. Write the responses on the board in the appropriate categories. Most group lists will include items relating to speed and motion. Briefly review the concepts of potential and kinetic energy when students name items related to the concepts.

Day 2 – Defining the Problem

Standards Addressed: 1, 9, 11

Essential Question: What are the constraints and criteria of the roller coaster project?

1. Before the start of the lesson, provide each group with the project binder which includes **Roller Coaster Design Project** information sheet (one copy per student), **Roller Coaster Budget** (one copy per binder), **Roller Coaster Simulation Notes** activity sheet (one copy per student), **Gallery Walk** activity sheet (two copies per binder), **Average Speed Calculations** activity sheet (one copy per student), and **Kinetic/Potential Energy Calculations** activity sheet (one copy per student).

2. Next, present to the class a completed roller coaster (either made by you or a previous class). Have one student roll the marble down the track a few times. As the marble goes down the track, provide an overview of the design criteria and constraints.

A NOTE FROM THE TEACHER

For this project, it is helpful to have a class website to house an online binder containing all project-related documents. It is also a useful tool to remind students about upcoming deadlines. Consider creating your class website using Edmodo *or* Google Sites.

3. Have students remove the **Roller Coaster Design Project** information sheet. Review the details of the roller coaster project. Explain the criteria and constraints of the roller coaster, as well as the budget.

A NOTE FROM THE TEACHER

Consider putting students in groups before they begin the project. I use the Myers-Briggs Type Indicator to determine student personality types. Based on the results, I group students who may work best together.

4. Review the different jobs for the projects: Accountant, Supply Manager, Cleanup Manager, and Presentation Manager. Explain each project job, and give groups time to discuss and choose jobs.

5. Have the class to ask clarifying questions and make sure to address questions and concerns about the project.

Day 3 – Conducting Background Research: Applying Potential and Kinetic Energy

Standards Addressed: 1, 6, 7

Essential Question: What are the different types of energy?

1. Pique student interest as they walk in by handing them a piece of candy, which gets them excited and curious. When students ask why you gave them candy, let them know that it relates to the roller coaster project and the concepts on forces, motion, and work. Tell them not to eat the candy until you say so.

2. Introduce learning targets and giving an overview the Law of Conservation of Energy. Begin by showing slides three and four from the **Types of Energy PowerPoint**.

3. Next, review the specific types of energy by showing slides five through seven from the **Types of Energy PowerPoint**. There are checks for understanding (CFUs) embedded throughout the presentation (slides 8 through 23). Ask for volunteers to answer the CFUs as they show.

4. After reviewing the concepts, ask for a volunteer to come up and manually wind up a flashlight until it turns on. Tell the students to work as a group for about 10 minutes to name all of the energy transformations involved in eating the candy to shining the light. As groups work, make sure to circulate and conference with the groups. Ask probing questions, such as: "What kind of energy does the wrapped candy start as?" "How does the potential energy of the candy create the kinetic energy of the lit flashlight?"

5. Once groups have worked for some time, ask for volunteers to share out the types of energy involved in lighting the flashlight.

Days 4-5 – Brainstorm and Evaluate: Roller Coaster Simulations

Standards Addressed: 4, 5, 7, 8, 10, 13

Essential Question: What can I learn from online simulations of roller coasters that will help me build my own?

1. Make sure to reserve a laptop cart or the computer lab for these two days.

2. Remind students of the roller coaster problem and explain that as part of their research, they will become designers. Explain that in the real world, simulation programs are often used to test out design possibilities before time and money is spent to build it.

3. Show the class the roller coaster module on the class website. Pass out the group binders. Have students remove the **Roller Coaster Simulation Notes** activity sheet from the binder (one per student)**.** Students will work individually to work through the following online roller coaster design simulators: PE-KE Simulation, Amusement Park Physics, Amusement Park with Explanations, Discovery Online Coaster, Fetch Online Coaster. In their notes, students should include observations about the roller coaster simulations. Altered factors include altering height of hills, slope of hills, number of hills, shape of track, shape of loops, speed, starting velocity, changing direction, changing mass, changing gravity. The goal is for students to design roller coasters that are fun and safe.

4. At the end of the lesson, ask for volunteers to discuss their experience and takeaways using the online roller coaster simulators. Have students put their completed individual sheets back in the group binder. Have students put their binders in the designated space.

Day 6-7 – Brainstorm and Evaluate: Roller Coaster Gallery Walk

Standards Addressed: 4, 5, 9

Essential Questions: What factors make a safe, fun, and stable roller coaster?

1. For the gallery walk, make sure to set up already made roller coasters throughout the room. If you do not have any premade roller coasters, consider setting up laptops around the room and using pictures of the roller coasters from Paper Roller Coasters. Make sure to include examples that are both structurally sound and structurally insecure and imbalanced. Examples should be different sizes (but within the height constraints). Plan to keep the display up for at least two days.

2. Remind students of the roller coaster problem and the project criteria and constraints to build a safe, secure and fun roller coaster. Review the next part of the EDP process (Brainstorming/Choosing Best Solution/Designing). Explain that they will be spending the next two days thinking about the most effective roller coaster design. Tell them that they will be walking around the class to look at what designs may work best to fit the criteria.

> ***A NOTE FROM THE TEACHER***
>
> *If this is your first year implementing the project, you may not have access premade roller coasters for the gallery walk. Consider setting up laptops around the room showing online simulations of roller coasters. Make sure to include simulations that are both strongly sound and structurally insecure and imbalanced.*

3. Before they begin, have students remove the **Gallery Walk** activity sheet from their binders (two sheets per group). In pairs, students will go on a gallery walk of the roller coasters for about fifteen minutes. Pairs will have a marble to test on each roller coaster. Each pair will evaluate each roller coaster's safety, stability of the structure, placement of required components, fun factor, speed, height, and any other factor that will help them get ideas for their own designs. Make sure to walk around and ask pairs probing questions regarding the structure, safety, fun factor, and adherence to the criteria and constraints.

4. After the gallery walk, pairs will return to their desks and come together as groups. Team members will share with one another their observations and start making a list of ideas to include in their own design on a blank sheet of paper that they will include in the binder.

5. At the end of the lesson, have students return their **Gallery Walk** activity sheet to their binders and then return the binders to the designated space.

Days 8-9– Brainstorm and Evaluate: Sketching a Roller Coaster Design

Standards Addressed: 9, 12, 13

Essential Question: What type of roller coaster should we build?

1. Have the presentation manager retrieve the group binder from the designated space.

2. Tell students that over the next two days, each student will sketch a roller coaster design idea for the structure and track, which they will propose to their teammates. From the sketches, each group will select one design to build for their final roller coaster.

A NOTE FROM THE TEACHER

Tell students that on day 10, you will open the Roller Coaster Supply Store and offer a 15% discount on the supplies. Encourage groups to settle on the supplies they need before the store opens, so that they can take advantage of the discount.

3. Have students remove their notes from the gallery walk, the list of ideas, and a couple of pieces of design paper per student. Distribute rulers. Let students know that they can revisit the gallery of roller coasters, if needed. Make sure to walk around and conference with individual students regarding their designs. Make sure to ask probing questions of each student's design, including questions about their structure and track choices.

4. After twenty minutes of sketching, students will share their ideas with teammates. Group members should discuss the designs until they choose a final group design solution.

5. Let students know that before they can move on to building, group members must all settle on one of the designs. Specifically, students must have a firm plan for the support beams, funnels, loops, etc. they will need to build their roller coaster design. See teacher note about the Roller Coaster Supply Store.

6. For groups having difficulty with selecting a design, provide guidance and ask probing questions, such as: "Which designs adhere to all of the constraints and criteria?" and "Which designs are more structurally sound than the others and why?"

7. Have students return their designs to the group binder. Have one group member return the binder to the designated space.

Day 10 – Develop and Prototype the Solution: Building the Roller Coaster, Part I

Standards Addressed: 9, 10, 11, 13

Essential Question: How do we budget for our roller coaster? What materials should we purchase for our roller coaster?

1. Tell students that today you will open the Roller Coaster Supply Store. Model how to score, cut, fold, tape and put together roller coaster pieces. Provide students with the manufacturers' instructions to make the roller coaster components. Explain that they may also change the pieces, alter the pieces, or use them creatively as long as the track is safe, stable, and adheres to the constraints and criteria.

2. Give students about ten minutes to decide on the materials that they will purchase. Remind students that although they will be able to purchase supplies on other days, this is the only day that they will be able to receive a 15% discount. Tell students to make sure they bring and complete the **Roller Coaster Budget** activity sheet with them when they purchase supplies. Open the store and start selling supplies to students.

3. After the initial wave of students purchase their supplies, begin circulating the room and conference with groups as they build. Ask probing questions regarding safety, structure, supplies, and fun factor.

4. At the end of the day, have student return their supplies, roller coasters, and binders to the designated space.

Day 11-15 – Develop and Prototype the Solution: Building the Roller Coaster, Part II

Standards Addressed: 9, 10, 11, 13

Essential Question: How do we build a roller coaster prototype?

1. Have the supply manager retrieve the supplies and roller coaster from the designated space. Have the presentation manager retrieve the group binder from the designated space.

2. Students should continue building the roller coaster, making sure to test, retest, and redesign (if necessary) as they build. Groups should be discussing problems and brainstorming solutions. They must keep the marble on the track by adjusting the slope or speed in some way and not by using artificial barriers or tape.

3. Make sure to monitor the store whenever students need to purchase supplies. When you are not in the store, make sure to circulate the room and provide feedback to group roller coasters.

4. At the end of each day, have students return their supplies, roller coasters, and binders to the designated space.

5. By day five, groups should be finished building the roller coasters.

Days 16-17 – Test the Solution: Calculating Average Speeds on the Roller Coaster

Standards Addressed: 2, 3, 5, 7, 8, 10

Essential Question: What is the average speed of our roller coaster?

1. Begin the lesson by testing a marble in an already finished roller coaster (either one that you built or from a previous class). Explain that the speed of a marble will increase and decrease many times depending on the slopes and loops. Explain that each group will need to find the speed of the marble in different portions of their roller coaster. Then groups will find the average speed of the marble during the entire trip down the paper roller coaster.

2. Have the supply manager retrieve the supplies and roller coaster. Have the presentation manager retrieve the group binder from the designated space. Instruct students to take out the **Calculating Average Speed of a Rolling Marble** activity sheet from the binder. Each student should have a copy. Read through each of the steps. Make sure to model each step for the class as you go through the instructions. Use slides two through eight from the **Calculating Speed and Energy PowerPoint** to provide a brief lesson on calculating average speed.

3. Groups will work together to calculate the speed of the marble between the different points. After each calculation, students should record the results on the table on the activity sheet. Circulate the room to conference with groups and assess understandings. Ask each group probing questions such as, "Which type of slope is the marble showing the fastest/slowest speed?" "Why do you think that is?" "What types of changes could you make to the roller coaster to increase or decrease the average speed of the marble?", and "Would your roller coaster's speed be a concern to potential riders, why or why not?"

4. After groups finish calculating the speed of the marble, they should work together to answer the questions about the speed of the marble. Students should complete the calculations, table, and graph as a group and the assessment questions individually on the activity sheets.

5. At the end of the class, collect the activity sheet from each group.

6. Have one student return the group binder to the designated space as they exit the classroom.

Days 18-19 – Test the Solution: Calculating Potential Energy and Kinetic Energy on the Roller Coaster

Standards Addressed: 2, 3, 5, 7, 8, 10

Essential Question: What is the potential and kinetic energy of our roller coaster?

1. Begin the lesson by showing a small demonstration of potential and kinetic energy (e.g. hold a ball and drop it). Ask students probing questions, such as: "At what point did the ball have the most potential energy?" "At what point did the ball lose its energy?"

2. Have the supply manager retrieve the supplies and roller coaster. Have the presentation manager retrieve the group binder from the designated space. Instruct students to take out the **Calculating Potential Energy and Kinetic Energy of a Rolling Marble** activity sheet from the binder. Each student should have a copy.

3. Give a brief lesson on potential and kinetic energy using slides 9 through 18 from the **Calculating Speed and Energy PowerPoint**. After the brief review, model how to

calculate kinetic energy. Use the review slides 19 through 23 to allow students some independent practice calculating energy.

4. Tell students that they will be calculating the change in potential energy of a marble traveling between two points on a paper roller coaster and compare that to the kinetic energy that the marble gained during that same time. Read through the instructions with students.

5. Students should work through the activity sheet by testing their marble and recording the data. Students should complete the calculations and table as a group and the assessment questions individually.

6. Make sure to walk around the room and conference with each group. Ask students probing questions, such as, "Which point of your roller coaster has the most potential energy and why?", "What average kinetic energy speed would be safer for potential riders?", and "What average kinetic energy speed would be more fun for potential riders?"

7. At the end of the class, collect the activity sheet from each group.

8. Have one student return the group binder to the designated space as they exit the classroom.

Days 20-21– Communicate Results: Presenting the Roller Coaster

Standards Addressed: 6, 11

Essential Question: How do we present our roller coaster prototypes?

A NOTE FROM THE TEACHER

Online presentations allow students to present the information without being present. Throughout the presentation, students will take video and photos documenting the build. Using the online presentation software, students can annotate images and video clips to explain different aspects of the project. Check with your district to find out if it has a subscription with an online presentation software.

1. Make sure to reserve a laptop cart or a computer lab for at least three days. The laptop cart is preferable since laptops can be placed next to the roller coasters on presentation day.

2. Have the supply manager retrieve the supplies and roller coaster. Have the presentation manager retrieve the group binder from the designated space.

3. Have students take out the **Roller Coaster Design Project** information sheet and direct them to the presentation guidelines on the last page. Tell students that now that they have calculated the speed and kinetic energy of the marble in their roller coaster, they will begin working on their interactive presentations.

4. Review the guidelines for the interactive presentation. Explain that these presentations will be alongside their completed

roller coaster. Explain that you and the class will use this presentation to help assess the success of the project.

5. As students work on their interactive presentations, walk around and conference with each group. Guide groups to critically assess their own roller coaster as they develop their presentations. Ask probing questions, such as: "Is this all of the information that someone would need to assess your roller coaster?" "What types of factors did you keep in your roller coaster that may be a concern to potential riders?"

6. At the end of each day, make sure students save all of their changes before signing out for the day.

Day 22 – Communicate the Results: Assessing the Designs

Standards Addressed: 6, 11

Essential Question: How do different roller coaster prototypes compare?

1. Have the supply manager retrieve the supplies and roller coaster from the designated space. Have the presentation manager retrieve the group binder from the designated space. Instruct students to bring the materials back to their desks.

2. Ask students to remove the **Roller Coaster Design Student Rubric**. Each group should only have one sheet. Explain to students that they will use the rubric to assess their peers' roller coasters. Review the assessment criteria, which includes design, budget, structure, safety, fun factor, adherence to the constraints, and interactive presentation. Explain that you will average your assessment with the class' assessments to arrive at the final score for the roller coasters.

3. Explain to students that they will have ten minutes to set up their roller coasters and interactive presentations. Once all groups have set up their roller coasters and presentations, instruct the groups to stay together as they circulate the room to assess the roller coaster designs.

4. Once students have had enough time to visit and assess each roller coaster, have them return to their seats.

5. Begin a group discussion of the various designs they assessed. Ask probing questions, such as: "What factors were included in the designs that you scored high in the fun factor?" "What factors were included in the designs that you scored low in the safety factor?"

Day 23– Final Assessment

Standards Addressed: All standards

1. Use the **Roller Coaster Design Teacher Grading Form** and **Roller Coaster Design Rubric** to grade each roller coaster. Calculate the score of out 150 (with five extra potential points for fun factor).