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Summary of Contents by Chapter

The egg drop activity is a classic physics classroom experience that is specifically mentioned in the *Next Generation Science Standards* (*NGSS*). However, with simple shifts in focus, it can also incorporate elements of engineering concepts and skills that are typically not addressed in a traditional physics classroom.

Chapter I: Justification

Teachers from the Greater Boston area share experiences of their own with infusing engineering, discuss some of the lessons learned, and offer some rationales for continuing to add engineering components to their classroom.

Chapter 2: Design, Analysis, Models, and Systems: Core Concepts for Engineering Infusion

Project Infuse focuses on four core concepts in engineering. Teachers can articulate different aspects and components in engineering practices that go beyond the general engineering design process.

Chapter 3: Implementation

Different experiences and methods have been developed by Project Infuse teachers. How can engineering be infused using the core concepts and engineering process in both larger project-based challenges and in smaller-scale anchor activities and case studies? The chapter ends with suggestions for timing, grouping, and structuring the classroom to make it more design-centered.

Chapter 4: Assessments

Engineering should be assessed alongside the science content. Teachers use rubrics to assess the quality of an engineering activity and the number of engineering concepts addressed and to self-assess the implementation of these engineering activities. This chapter explores the types of assessment for students and ways to support student success through a balance of assessing engineering process versus designed product.

Chapter 5: Engineering Infusion Using Anchor Activities

Brief activities that address specific engineering core concepts that can be used throughout the academic year.

Chapter 6: Engineering Infusion With Mechanics

Engineering-infused physics lessons that can be used throughout the mechanics unit. These address topics of forces, kinematics, and linear momentum and impulse.

Chapter 7: Engineering Infusion With Energy

Engineering-infused physics lessons that can be used throughout the energy unit. These address topics of mechanical energy, energy conservation, and thermal energy.

Chapter 8: Engineering Infusion With Waves

Engineering-infused physics lessons that can be used throughout the waves unit. These address topics of sound, light, reflection, and refraction.

Chapter 9: Engineering Infusion With Electricity and Magnetism

Engineering-infused physics lessons that can be used throughout the electromagnetism unit. These address topics of current electricity, electrical components, and magnetism.

Chapter 10: Professional Development and Growth in Engineering Infusion

The history of Project Infuse and how it supports professional development opportunities for groups of teachers to implement engineering concepts into the classroom.

Engineering Infusion With Mechanics

A natural place to start infusing engineering in the physics classroom is with some existing projects in the mechanics unit. Mechanics is the most straightforward place to try engineering infusion activities and certainly offers many possibilities from which to choose. Some of the activities in this chapter are designed to introduce and explore specific content such as Newton's laws or kinematics. Others are meant to be culminating activities or performance assessments to demonstrate what students have learned.

Look at the balloon cart and mousetrap cars activities if you want a theme that ties together an entire mechanics unit. Alternatively, you might decide to start with a no-cost engineering infusion to understand transfer of momentum, and design amusement park bumper cars using only a computer and a PhET simulation. Have you always done an egg drop project but want to add some engineering rationale to it? Introduce it with some clips from the movie *The Martian,* ask students to identify and explain how Mark Watney analyzed his engineering problem, and then connect Watney's analysis to students' own analyses for their egg drop designs.

If teachers have the luxury to select and use many different activities, choose ones that complement one another by focusing on different aspects of engineering. Begin the forces unit by asking students to analyze different materials for a trampoline, then end with a project where students are asked to consider all the net forces acting on an aluminum foil boat. Table 6.1 (p. 118) provides basic curricular details for the seven activities in this chapter.

TABLE 6.1. Chapter 6 Activities

Activity Name	Physics Concept(s)	Core Concept(s)	Class Period(s)	Brief Description
Balloon Cart Project	• Distance • Time • Velocity • Newton's laws • Energy	• Design • Analysis • Models	2–3	Use limited materials to design a balloon-powered cart that travels three meters in less than five seconds.
Newton's Third Law Paper Trampoline	• Newton's third law • Forces	• Analysis	1	Learn about Newton's third law by testing fabrics and other materials for a trampoline designed to provide the highest possible bounce of a steel ball.
Bristlebots	• Distance • Time • Velocity • Vectors	• Design • Analysis • Models • Systems	1	Use a toothbrush, a small motor, and some wires to make a bristlebot, then optimize it for maximum displacement.
Mousetrap Car Challenge	• Motion (kinematics?) • Force	• Design • Models • Systems	4	Design a mousetrap-powered car that goes the fastest down a narrow racetrack.
Amusement Park Engineer–Bumper Cars	• Momentum	• Design • Analysis • Models	3	Using PhET simulation, create a proposal for design of a set of bumper cars that are safe, fair, and fun for children, teenagers, and adults.
Egg Lander–Motion Design CEPA	• Impulse	• Design • Analysis • Models	4	Design a vehicle that successfully lands an egg dropped from a height of two meters. Use force plates, motion detectors, and other tools for analysis along the way.
Golf Ball Boat	• Net force • Buoyancy	• Design • Models	3	Use a 30 cm × 30 cm piece of aluminum foil to construct a boat that supports the weight of the largest number of golf balls.

ACTIVITY 6A: BALLOON CART PROJECT

Contributor: David Scott and Peter Schoonmaker

Time frame: 2–3 class periods
Physics focus: Newton's laws, momentum, and energy
Engineering focus: Design, analysis, and models

Opportunities for Science Versus Engineering Concepts

Concept	Science	Engineering
Design	• Air-to-distance ratio • Different types of wheels and grips on the car (friction) • Various masses	• Design a balloon cart using engineering skills to satisfy certain criteria. • The design must use the limited materials allowed and meet the constraints given by the challenge.
Analysis	• Free-body diagram • Momentum • Energy • Newton's second law of motion • Kinematics • Newton's third law pair	• Mechanical analysis: structure and rigidity • Adjustments that are useful for the design goal • Analysis of materials, including materials' failure points • Ways to reduce friction • Directional stability
Models	• Gas model (molecular model of the gas) • Full-body diagram • Friction and air resistance • Depiction of Newton's third law forces • Average force is constant • Mass or massless gas	• Simulation of a small-scale vehicle
Systems	• Car versus external force (air) (i.e., the system is different when the car is in the air versus when it is on the floor)	• Balloon system • Wheel system • Connection (structural support)

PROJECT OVERVIEW

Instead of teaching students about Newton's laws, momentum, and energy through several individual units, you can use this balloon cart project during each unit. It also works well as a capstone activity that ties all of those units together for the students. The balloon cart project covers many of the topics that typically are on mid-year examinations, and students will see it as a fun and competitive activity to perform just before those examinations. In addition, it will enable students to apply what they have learned while they accomplish a challenge in which they can see how making small adjustments to their design will affects the balloon cart's performance.

THE CHALLENGE

Students work in pairs and must design and build a balloon-powered cart capable of traveling a specified distance (typically three meters) in a specified time frame (typically five seconds) using only the materials provided. If they accomplish this, they have successfully completed the challenge. Bonus points are awarded to the team whose balloon cart travels the farthest and to the team whose balloon cart travels the specified distance in the shortest time.

On the first day of the challenge, students are told the rules and shown the materials that they will be given. They should not be given the supplies right away, because they will immediately start trying to build something without thinking it through. The only hint provided is that the balloon is fairly small and thus only provides a small puff of air. To be successful, students must think about all aspects of their design. Typically, it takes 20–30 minutes to develop a design, and another 20 minutes to develop three drawings (front, top, and side views). The teacher must approve the design and drawings before students receive their supplies. There are always flaws in the design, but they can be left to be discovered by the students. However, occasionally a design is so flawed that the teacher should provide some guidance for improvement. When the students' design is complete, they may be given the materials and may construct their balloon cart.

The second day begins with students building the carts. The first prototype is usually very rough—students will have given little thought to how to make the cart go the farthest or travel the fastest. The first brave team finally approaches the teacher usually about 20 minutes into the class, ready to test its cart. The trial area will have been marked on the floor with two pieces of masking tape three meters apart, one labeled "Start" and the other "Finish." A first design may look like this: the entire index card is used, the skewer has been cut in half and used as an axle, the wheels are on crooked, and the balloon is taped to the index card at the balloon's widest part—this cart has *no* chance. The entire class is watching this pioneer team with anticipation as students blow up the balloon, put the cart down, and release the balloon. The cart moves about six inches before the balloon shrinks enough to become unattached and fly off. Everyone laughs, but everyone has also learned that the balloon cannot be taped directly to the cart, at least not at the balloon's widest part. The remainder of the second day is spent with each team testing its design and everyone else standing around watching and learning what works and what doesn't.

Eventually, a common design begins to emerge. The skewer is cut into two pieces and the straw into three pieces. Two pieces of the straw are taped to the bottom of the index card and the skewers are slipped inside the straws. The wheels are attached to the skewers and both rotate with very little friction between the skewer and the inside of the straw. The third piece of straw (preferably the piece containing the flexible portion) is used to secure the balloon to the index card. The balloon is placed over the flexible portion and taped to the straw. The straw can then be taped to the rear of the index card to provide the force to move the cart. If the straw hangs over the edge, the balloon can be inflated through the straw.

Even though the design appears as though it should work, there are still a number of potential problems, mostly related to sloppy construction. These include the following:

- Wheels are not centered properly, causing them to wobble, which creates a slight force in the wrong direction.
- The straws are taped on crookedly, so the cart doesn't travel in a straight line.
- Wheels rub against the index card, causing friction.
- There is too much mass for the balloon to overcome.

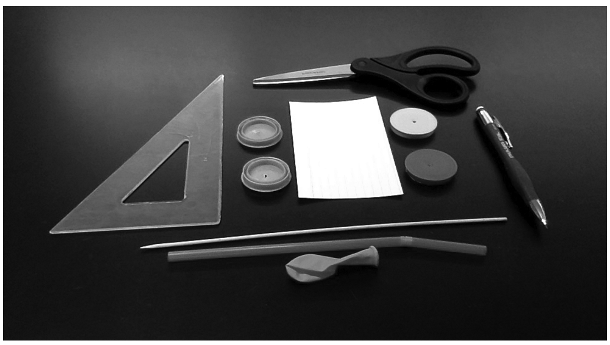
Eventually, teams complete the challenge successfully, but then want to modify their cart try to gain the bonus points. Someone will finally recognize that Newton's second law is in play and realize that to win the bonus points for fastest time, they must reduce their cart's mass. They begin trimming the index card in half widthwise, cutting off as much of the skewers as possible, and eliminating anything else to decrease the mass. This cart retests and, sure enough, it has the fastest time. Another team decides that if reducing the mass a little is good, then reducing it by even more must be even better. They cut their index card in half not only widthwise but also lengthwise. When they retest their cart, it flies around in a circle or flips over. They went too far and the cart lost all stability.

The third day is spent finishing testing for one or two groups and then developing lab reports. The lab reports describe students' design process, how they arrived at their initial design, how it was modified over the course of the activity, and why. Students need to include their design drawings and an analysis report that includes the following information:

- The cart's
  - Time to cover three meters
  - Total distance traveled
  - Total time of travel
  - Average speed over three meters
  - Mass and weight
  - Average momentum over three meters
  - Average kinetic energy over three meters
  - Potential energy at the beginning (hint: conservation of energy)
  - Average acceleration over three meters
- The average force acting to stop the cart (hint: impulse)
- The total work done (hint: work–energy theorem)
- A paragraph explaining Newton's third law and how it applies to the cart's motion (or, explaining how impulse and momentum relate to the motion)
- A paragraph explaining Newton's second law and how it applies to the cart's design and motion

BIG IDEAS

- **Physics:** Energy is a quantitative property of a system, which can affect the motion of an object. Increases in energy can cause an object to accelerate or to perform some form of work. When a system performs work, the total energy of the system decreases.
- **Engineering:** Engineers use models to confirm mathematical or hypothetical designs. Models typically require a number of design modifications to make corrections to the original design or incorporate improvements on the basis of empirical data.



The raw materials for the first balloon car prototype