BEYOND THE EGG DROP

Infusing Engineering Into High School Physics

Arthur Eisenkraft
Shu-Yee Chen Freake
Editors

NSTA press
National Science Teachers Association

BEYOND THE EGG DROP

INFUSING ENGINEERING INTO HIGH SCHOOL PHYSICS

BEYOND THE EGG DROP

Infusing Engineering Into High School Physics

Arthur Eisenkraft
Shu-Yee Chen Freake
Editors

NSTA press
National Science Teachers Association
Arlington, Virginia

NSTA press®
National Science Teachers Association

Claire Reinburg, Director
Rachel Ledbetter, Managing Editor
Deborah Siegel, Associate Editor
Donna Yudkin, Book Acquisitions Manager

Art and Design
Will Thomas Jr., Director
Himabindu Bichali, Graphic Designer, cover and interior design

Printing and Production
Catherine Lorrain, Director

National Science Teachers Association
David L. Evans, Executive Director
David Beacom, Publisher

1840 Wilson Blvd., Arlington, VA 22201
www.nsta.org/store
For customer service inquiries, please call 800-277-5300.

21 20 19 18 4 3 2 1

NSTA is committed to publishing material that promotes the best in inquiry-based science education. However, conditions of actual use may vary, and the safety procedures and practices described in this book are intended to serve only as a guide. Additional precautionary measures may be required. NSTA and the authors do not warrant or represent that the procedures and practices in this book meet any safety code or standard of federal, state, or local regulations. NSTA and the authors disclaim any liability for personal injury or damage to property arising out of or relating to the use of this book, including any of the recommendations, instructions, or materials contained therein.

Library of Congress Cataloging-in-Publication Data
Names: Eisenkraft, Arthur, editor. | Freake, Shu-Yee Chen, editor.
Title: Beyond the egg drop : infusing engineering into high school physics / edited by Arthur Eisenkraft and Shu-Yee Chen Freake.
Description: Arlington, Virginia : NSTA Press, National Science Teachers Association, [2017] | Includes bibliographical references and index. | Identifiers: LCCN 2017046075 (print) | LCCN 2017053321 (ebook) | ISBN 9781681400365 (e-book) | ISBN 9781681400358 | ISBN 9781681400358q(print) | ISBN 1681400359q(print)
Subjects: LCSH: Physics--Study and teaching (Secondary) | Engineering--Study and teaching (Secondary)
Classification: LCC QC30 (ebook) | LCC QC30 .B49 2017 (print) | DDC 530.071/2--dc23
LC record available at *https://lccn.loc.gov/2017046075*

CONTENTS

CONTENTS

Preface

Arthur Eisenkraft

The "egg drop" is certainly a fun activity. Students are charged with designing packaging for an egg that will allow it to be dropped from a height of five meters onto a concrete floor without being damaged. The drop is even more fun—and messy—if students forget to first wrap the egg in a plastic bag. But, is this science? Is it engineering? The project is used in science classes and asks for an engineering design. But is that enough to qualify it as engineering?

The egg drop project can be given to engineers. The engineers will certainly use physics principles in solving this design challenge. They will bring to this problem an understanding of materials, design, and analysis. They may build prototypes and test them as part of their work. How do we assess students along the lines of how engineers would address this challenge? As teachers, how can we clarify our directions and alter our expectations so that the high school engineering students become student engineers? How can we interweave opportunities to learn engineering concepts and skills in an already packed science curriculum?

Using engineering design principles and engineering terminology (e.g., the following boldface terms) can move this activity closer to meeting the criteria for an exemplary engineering lesson. In the challenge to **design** packaging for an egg, we can include additional **constraints** to the given **criterion** of surviving the impact of the concrete floor from a drop height of five meters. For example, we can limit the packaging material to one piece of paper and one meter of masking tape. We can require the students to come up with three possible designs, and then choose their **optimum** design and provide **justification** for their choices. We can allow them multiple **iterations** of their design after **testing** from a height of one meter, requiring them to record in their **engineering notebook** their **analysis** of the present design and the reason for each **modification**. We can insist that they include the relevant **physics principles** such as impulse, force, time, and change in momentum and how their design takes these physics principles into account. But even this is not enough.

Engineering is defined in *A Framework for K–12 Science Education* (the *Framework;* NRC 2012, p. 11) as "any engagement in a systematic practice of design to achieve solutions to particular human problems." In asking the students to design packaging for an egg, the teacher should provide a rationale for the request. The rationale for an engineering design project is crucial. Who wants to protect this egg? Why is anyone dropping eggs onto concrete from five meters up? What is the human problem we are trying to solve? Are we really concerned that people are dropping eggs from five-meter heights onto concrete and the eggs are breaking? Of course not! However, we do know that when we buy a carton of eggs at the market, one or more eggs may be cracked or broken. The safe transportation of eggs is a problem and we have to decide how to test packaging. Packaging eggs for safe transport is one valid rationale. But the rationale for our engineering design may not be about eggs at all. We may be devising an improved safety device for a car. When testing this device, we can use the egg as a model for the human skull. If we can keep the egg safe, then we can assume that the human skull would also be safe. This, of course, depends on whether an egg is a useful **model** for a skull. Exemplary engineering projects are not contrived situations, and with a bit of effort, teachers and students can create the rationale for why students are engaging in the design challenge.

The *Framework* and the *Next Generation Science Standards* (*NGSS;* NGSS 2013) demand that engineering be a part of a student's education. One solution to this requirement is to adopt or create engineering courses in high schools. Some schools have been inventing or adopting a number of curricula. These courses require students to find room in their programs to enroll in such a course for a semester or more. Some of the curricula available are quite engaging and comprehensive. Given the staffing constraints in many schools and the impossibility of adding another course to some students' schedules, we advocate for a different model—infusion of engineering into all science courses.

Adopting the engineering infusion model implies that all students enrolled in science courses will get exposure to engineering and a sense of the interplay between science and engineering. Science and engineering coexist in our culture. We need engineers to help invent technologies to allow science to proceed. We need scientists to uncover new areas of knowledge and to develop new theories so that engineers can invent new technologies to solve problems. Too often in school instruction, engineering and technology are either ignored in the curriculum or seen as the handmaiden of science. The infusion model addresses this problem and brings out the rich relationship between the two subjects.

This book explores the model of infusing engineering into high school physics or physical science courses. Most of the book provides lessons that can be incorporated throughout the school year. The lessons vary in length. Some require only a part of a class period, while others require a full class period. Some are longer projects that go on for days or weeks. Sometimes those lessons are activators and are best used before any discussion of physics principles. Others are capstones and are best used after the physics lessons have been completed. These lessons have all been tested and are accompanied by artifacts of student work so that other teachers can get a better sense of student expectations.

The *Framework* and *NGSS* reference engineering design. Research shows that engineers have reached a consensus on the most important features of engineering. We will use those four features—design, analysis, modeling, and systems—to help frame engineering lessons. All science teachers will recognize that these same four terms are used throughout science instruction. Teachers and students should be able to distinguish between the uses of these terms in their different contexts. The following are examples:

- How are engineering models similar to and different from scientific models? An engineering model of an airplane is quite different from the scientific atomic model. The models also serve different purposes.
- How does one compare and contrast engineering systems and systems in biology or physics? In designing a new sound system, one engineer may focus on the electrical system, another may focus on the mechanical system, and a third may focus on the safety system. Biologists invent systems to help them understand the human body. They define the digestive system and the endocrine system but do not define the "left leg" system. Physicists use isolated systems to simplify the problem.
- Engineers design a product (e.g., a safety device for a car) that must meet certain constraints. Physicists design an experiment to find the relationship between variables (e.g., how does the stopping distance of a car relate to its speed?).
- Analysis is an important component of both engineering and physics. Engineers will use analysis to determine the type of fastener to use for a given situation. Physicists will use analysis of Newton's laws to determine the stability of an object on a ramp.

All of these are important distinctions that teachers should be able to articulate for students to understand these overlapping engineering and science concepts.

Through the lessons presented in this book, we articulate the use and examples of the terms—*design, analysis, models,* and *systems*. Among the lessons are "anchor activities" that can be used to provide a foundational understanding of these terms in engineering. Each anchor activity provides a memorable example of design, analysis, models, or systems. Each engineering-infused activity in the book includes a chart that will show the unique use of each of these terms.

Presenting engineering-infused lessons in not enough. Assessment must play a central role in the infusion of engineering into physics. The larger issue of assessment has three facets, which are all considered in this book: assessment of lessons, assessment of teaching and assessment of student learning. Each affects the others but uses a unique rubric.

Assessment of lessons has to do with the quality of the engineering activities. How does a teacher decide whether a lesson found on the internet in which students drop an egg onto concrete represents a high-quality engineering activity? What criteria should be reviewed? How can teachers modify and improve what they find? Rubrics are provided in this book to help guide teachers in the adoption of engineering-infused activities.

Assessment of teaching focuses on teacher practices. How should a teacher introduce an engineering design challenge? How much time should a teacher allocate to engineering principles? Should the engineering infusion activity be positioned before the science, during the science or after the science? How much help should a teacher provide students? At what point during the student design work should teachers make suggestions? How much time should students be provided to complete a design challenge? These questions are discussed here in general and then articulated through the sample lessons that follow.

We discuss assessment of student learning, as well as the difficulties inherent in any such an evaluation. For example, do we want to assess the product that the students submit or are we more interested in the process that got them to the product? If one student group converges on a single design, executes it, and has a product that meets the criteria, what grade does it get? If another student group looks at multiple solutions, chooses the best one (and defines why it is best), and pursues this through a number of iterations but fails to have a final product that meets the criteria, what grade does it get?

We begin the book with an example of an exemplary infusion of engineering and contrast it with a lower-quality infusion. We then discuss the role of engineering in the *Framework* and *NGSS*, and make distinctions between engineering and trial and error. Then we introduce approaches to engineering infusion. We discuss the themes of design, models, systems, and analysis and make distinctions between how these terms are used in science and in engineering. Finally, we introduce the three facets of assessment.

The major focus of the book is the classroom-tested engineering-infused lessons. Along with each lesson, we provide a detailed description of why teachers should consider adding the lesson to their science curriculum. We then present examples of student work to illustrate the demands the different lessons make on high school students at different times. The lesson plans are presented in the major content areas of physics and those given in the *Framework* and *NGSS*.

We close with suggestions to readers for how they can involve other teachers and students in the infusion of engineering into high school physics and physical science courses.

As teachers, we must take many things into consideration as we develop our curriculum. Every day, there is more science in the news that we could use to engage students. We must decide which current events to bring into the classroom or whether to debate a scientific controversy. Some may ask whether engineering infusion will push out some of the physics or physical science curriculum. No science teacher wants to give up valuable lessons just to include another topic in their curriculum. We think that engineering infusion is different in that instead of taking away from time on a subject, it will enhance the science we get to present and provide students with additional understanding of science concepts. This book is our attempt to find out if we are on the right track.

REFERENCES

National Research Council (NRC). 2012. *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards.*

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.

About the Editors

Arthur Eisenkraft, PhD, is the distinguished professor of science education, professor of physics, and director of the Center of Science and Mathematics in Context at the University of Massachusetts (UMass) Boston. He is past president of the National Science Teachers Association (NSTA) and is past chair of the Science Academic Advisory Committee of the College Board. Eisenkraft is also project director of the National Science Foundation (NSF)–supported *Active Physics* and *Active Chemistry* curriculum projects, which introduce high-quality, project-based science to *all* students. In addition, he is chair and co-creator of the Toshiba/NSTA ExploraVision Awards, involving 15,000 students annually. Eisenkraft also leads the Wipro Science Education Fellowship program, which is bringing sustainable change to 20 school districts in Massachusetts, New Jersey, New York, and Texas, and he has recently been supporting novel educational initiatives in Thailand and India.

His current research projects include investigating the efficacy of a second-generation model of distance learning for professional development—a study of professional development choices that teachers make when facing a large-scale curriculum change—and assessing the technological literacy of K–12 students.

He has received numerous awards recognizing his teaching and related work, including the National Public Service Award, the Presidential Award for Excellence in Mathematics and Science Teaching, the American Association of Physics Teachers Millikan Medal, the Disney Corporation's Science Teacher of the Year, and the NSTA Robert H. Carleton Award. He is a fellow of the American Association for the Advancement of Science, holds a patent for a laser vision testing system, and was awarded an honorary doctorate from Rensselaer Polytechnic Institute.

Shu-Yee Chen Freake has taught physics and biology at Newton North High School (NNHS) in Newton, Massachusetts, since 2005. She has a BS in biology, with minors in physics and education, from Brandeis University. She also holds an MEd from Northeastern University. At NNHS, she has taught a wide range of levels in both physics and biology. As a secondary educator, she is constantly looking for ways to engage students, focusing mainly on scaffolding learning experiences that promote student science and engineering skills that are necessary to solve problems in novel situations. She field-tested the NSF-funded Energizing Physics curriculum, which led to her interest in incorporating engineering pieces into the physics curriculum. In 2014, she was part of a team that developed videos to demonstrate reflective teaching through a grant funded by the Massachusetts Department of Elementary and Secondary Education. In this project, she taught and revised a physics and engineering lesson as part of a professional learning community. Since 2012, she has been involved in the Project Infuse program as a participant for the first cohort and then a co-trainer for the second cohort. She has presented at NSTA conferences, and helped in the planning and writing of this book.

Note: This work was supported primarily by NSF (Award Number 1158615). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect those of NSF.

Contributors

PROJECT INFUSE LEAD TEACHERS

Arthur Eisenkraft, Kristen Wendell, Shu-Yee Chen Freake, and Derek van Beever

PROJECT INFUSE GANG (TEACHERS OF COHORTS I AND II)

Robert Aldape, Alexandra Allaire, Paul Aylward, Jacob Backon, Kevin Brosnan, David Carbonneau, Nivedi Chandrasekaran, Blair Cochran, Emma Dalton, Marna Eckels, Gita Hakerem Foster, Ashley Freeman, Boris Gokhfeld, Andrew Goodman, Michael Hazeltine, Neil Kenny, Julie Mills, Norman Mitchell, Catherine Haberkorn Newman, Kristin Newton, Nora Paul-Schultz, Danielle Raad, David Scott, Valentina Sountsova, Peter Spiers, and Amy Winston

PROJECT INFUSE LEADERSHIP TEAM

Rod Custer, Jenny Daugherty, Deb Brockway, Arthur Eisenkraft, Katheryn Kennedy, and Julie Ross

OTHER CONTRIBUTORS TO WORKSHOPS

Cory Culbertson and Sanjoy Mahajan

See the "More About the Contributors" section (p. 457) for additional information about some of the individuals listed above.

8

Engineering Infusion With Waves

The *Next Generation Science Standards* (*NGSS*) have a strong emphasis on the important, yet mostly invisible, topic of electromagnetic radiation. It is difficult for students to understand the concepts of waves and wave energy without some tangible and meaningful experience exploring properties of waves. We wanted to ensure students have a strong foundation in the properties of waves, and since it is difficult to manipulate all the frequencies of electromagnetic waves easily in the classroom, concrete design activities that require a strong understanding of wave properties and wave model are a great option to help students gain understanding.

Before beginning a waves unit, take out a guitar and ask students, "What are some considerations engineers have to think about when designing a musical instrument?" The design of the instrument goes way beyond just making some vibrations, allowing users to easily tune the guitar in order to make beautiful sounds of different pitch and clarity. Ask students to extend their understanding of the wave model by looking at light as a wave. Why not ask them to evaluate criteria for a fun game or toy when they design a game using lenses and mirrors? The client-centered aspect of engineering can be the real motivator for many students, encouraging higher engagement than a traditional physics lab of working with tuning forks and drawing reflective rays on paper.

The pendulum activity is an interesting attempt at infusion, where the first portion is like a physics pendulum lab for understanding period and length. Then, the engineering challenge is added by asking students to match the pendulum to a beat and make a pendulum that can produce a sound at the top of the swing. Table 8.1 (p. 290) provides basic curricular details for the activities in this chapter.

TABLE 8.1. Chapter 8 Activities

Activity Name	Physics Concepts	Core Concepts	Class Periods	Brief Description
Pendulums–And the Beat Goes On	• Period • Frequency • Simple harmonic motion	• Design • Analysis	3	Students build a pendulum that acts as a metronome to keep pace with the beat of a song.
Guitar Design Project–Exploring How Music Is Made	• Sound • Wave properties	• Design • Analysis • Models	2	Students use household items to make a functional guitar that can play at least one octave and a song.
Game On!	• Refraction • Reflection	• Design • Analysis • Models • Systems	3	Students design a board game that uses mirrors and lenses and demonstrates students' understanding of optics concepts.

ACTIVITY 8A: PENDULUMS—AND THE BEAT GOES ON

Contributors: Julie Mills, Marna Eckels, and Neil Kenny

Time frame: 3 class periods
Physics focus: Pendulum motion, period, and frequency
Engineering focus: Design, models, iteration, test, and evaluate

Opportunities for Science Versus Engineering Concepts

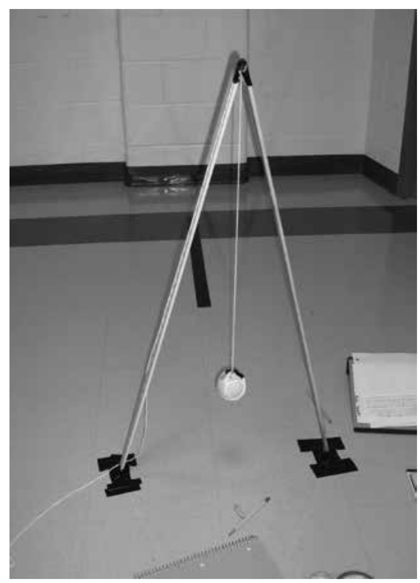
Concept	Science	Engineering
Design	• Period versus length	• Design a functional pendulum that makes a clicking sound.
Analysis	• Angle of the pendulum • Graphic analysis • Period • Frequency	• Materials analysis for strength, loss of energy from the sound • Physics analysis to make prediction and inform design
Models	• Simple harmonic oscillation • Wave model • Energy transfer	• Model for clock, metronomes
Systems	• Pendulum itself as a system • Energy	• Swing system • Weight system • Click system

PROJECT OVERVIEW

For an introductory physics course, pendulum motion can be a great segue topic between motion and waves. This engineering design challenge has components of the more traditional physics lab—in which students must determine how various factors affect a pendulum's period—but also includes an engaging engineering challenge.

The traditional physics pendulum lab asks students to test variables of length, mass, and angle to determine how these factors affect the period of a pendulum. For this engineering design challenge, students must build a pendulum that will act as a metronome, keeping time to a song of their choice. Because they probably do not have much prior knowledge of what factors affect the period of a pendulum, they must spend the first part of the activity determining how to adjust a pendulum to change its period. The first part of this activity more closely matches an inquiry-based physics lab. Students must gather data in a data table and present their findings in graph form for the class. When all groups have presented their findings, a consensus is found as to which factor or factors affect the period of a pendulum (length) and which do not (mass and angle). Students are asked to apply this new knowledge in an engaging way.

The engineering challenge portion of this activity asks students to find a song (school-appropriate is typically the only criterion) and to create a pendulum that keeps the beat to the song for at least 10 swings. Songs can be played using any electronic device available in the classroom. Finding the beat of a song can be tricky for some students, so we suggest beginning this project by asking students to rank themselves, on a scale of 1 to 10 , on their ability to find and clap to the beat. This helps create groups of mixed ability, ensuring that there won't be a group that is unsuccessful because its members can't determine the beat of a song. After students pick a song, they must determine the beat of the song and then create a pendulum that swings to the beat. Because they know that length is the only factor that affects the period, this engineering portion usually takes less than one class period. At a designated time, groups will present their pendulum–song combination to the class.



Students' initial prototype of the pendulum

The complexity (and the engineering aspect) can be enhanced by requiring students to create a pendulum metronome that makes an audible click for each swing (much like an actual metronome).

Throughout the project, students are collecting data and making calculations in their engineering notebooks. The graphs are created and inserted in the notebook. Summary questions that need to be answered by the students are provided. The rubric for this project is on the student handout (p. 302) and assesses students in the areas of data collection and calculation, graphs, written answers to the questions, and metronome performance.

BIG IDEAS

- **Physics:** Energy cannot be created or destroyed but can be converted to different forms—potential to kinetic to sound.

- **Engineering:** Design is an iterative process that can be used to produce a product. Testing and evaluating prototypes can provide essential feedback that leads to changes and refinements in the design.

Connection to the *Next Generation Science Standards*

Performance Expectations

- HS-PS3-2: Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).
- HS-PS3-3: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

Science and Engineering Practices

- Asking questions and defining problems
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathemats and computational thinking
- Constructing explanations and designing solutions
- Obtaining, evaluating, and communicating information

Disciplinary Core Ideas

- PS3.A: Definitions of Energy
- PS3.D: Energy in Chemical Processes and Everyday Life
- ETS1.A: Defining and Delimiting Engineering Problems

Crosscutting Concepts

- Patterns
- Cause and effect

Assessment: Determining Acceptable Evidence

Formative

- Group presentations of data and graphs
- Class discussion

Summative

- Individual: engineering notebook grading using rubric

Materials and Preparation

Materials (Groups of 2)

- Safety glasses or goggles for each student
- Meter stick
- Various masses
- String
- Protractor
- Ring stand
- Ring
- Electronic device to play music
- Scissors
- Stopwatch

Students ready to collect data again after modifying the length of the pendulum from previous trials

Safety

- Remind students about general lab safety procedures.
- Participants should wear personal protective equipment (eye protection) during the setup, hands-on, and takedown segments of the activity.
- Use caution in working with sharps (scissors), which can cut or puncture skin.
- Keep feet free of swinging masses in an oscillation pattern—this could injure feet.
- Make sure objects are removed from the path of the oscillation pattern.
- Participants should wash their hands with soap and water upon completing this activity.

Pendulums–And the Beat Goes On Lesson Plan for Day 1 (55-minute block)

Time Allotted and 7e Model Stage(s)	Lesson Procedure: What Are the Students Doing?	Instructional Notes: What Is the Teacher Doing?	Physics Opportunities	Engineering Opportunities
2 mins. **Engage**	—	• Play a popular song and have the students clap to the beat.	—	—
8 mins. **Elicit**	• Answer the Do Now questions. • Consider, What is a metronome and what is it used for? • List as many things they can think of that keep a steady beat or make a steady motion. • Write answers to Do Now questions individually and then share during class discussion. • Rank themselves on a scale of 1–10 on their ability to find and clap to the beat of a song.	• Elicit prior knowledge by writing the Do Now questions on the board for students to answer as they enter the room. • Have a metronome in the classroom or an online metronome available for demonstration in class. • Engage students through class discussion of the Do Now questions. • Introduce the concept of a metronome while introducing the goal of the project. • Use students' self-rankings of beat-finding ability to create heterogeneous groups.	• Period • Frequency • Harmonic motion	• Give students opportunities to do some initial brainstorming of ideas. • Encourage students to draw their initial designs on paper no matter how out-of-the-box they sound.
10 mins. **Explain**	• Read through the handout that explains the project and goals. In groups, gather materials.	• Explain to students the purpose of the activity and its two parts. • Facilitate the grouping of students and the gathering of materials.	—	—
35 mins. **Explore**	• Complete some of part 1 of the activity and enter data into their engineering notebooks. If time permits, graph data in class (or for homework).	• Facilitate the lab process for students as needed.	• Data collection • Period • Frequency • Harmonic motion • Graphing • Calculations	• Encourage students to break down the problem and perform analysis using mathematical models.
Elaborate **Evaluate**	**Homework:** Complete graphs of collected data.			

Pendulums–And the Beat Goes On Lesson Plan for Day 2 (55-minute block)

Time Allotted and 7e Model Stage(s)	Lesson Procedure: What Are the Students Doing?	Instructional Notes: What Is the Teacher Doing?	Physics Opportunities	Engineering Opportunities
40 mins. **Explore** **Explain**	• Continue to complete part 1 of the activity and graph results on chart paper or individual white boards. • In groups, present their findings for the effects of length, mass, and angle on the period of a pendulum.	• Facilitate the activity, visiting each group to make sure they are pacing themselves appropriately.	• Data collection • Period • Frequency • Harmonic motion • Graphing • Calculations	• Students use the mathematical model created to fine-tune their understanding of this engineering design problem.
15 mins. **Explain** **Elaborate**	• In groups, present their findings to the class, explain their results, and elaborate on how they determined their results. • One student should summarize findings on board. • After analyzing all of the data together, answer a posed question in their engineering notebooks.	• Facilitate the sharing of information and the class discussion.	• Communicating results	—

Pendulums–And the Beat Goes On Lesson Plan for Day 3 (55-minute block)

Time Allotted and 7e Model Stage(s)	Lesson Procedure: What Are the Students Doing?	Instructional Notes: What Is the Teacher Doing?	Physics Opportunities	Engineering Opportunities
10 mins. **Elaborate Evaluate**	• In groups, gather materials and determine which song they will use for the challenge. • For their chosen song, measure the beats per minute (frequency) of the song and calculate the period of the metronome pendulum.	• Facilitate the choosing of the songs and the frequency and period measurement. • If desired, give a brief review of frequency and period relationship. • *Note:* Frequency units are typically given as Hertz (beats per second); however, song frequencies are described at beats per minute. If appropriate, include a brief explanation of the difference and the relationship.	—	• Students have an opportunity to use any tools to measure and analyze the beats of the song.
30 mins. **Explore Evaluate**	• In groups, use the information gathered from part 1 of the activity to construct a pendulum that can keep the beat for 10 swings.	• Facilitate the design and build process.	• Efficiency of energy transfer	• Engage students in the engineering design process, emphasize the importance of iteration, and ask students to consider how to solve the two competing criteria (making a sound versus having a constant swing). Working with competing criteria is often part of the engineering design process.

Pendulums—And the Beat Goes On Lesson Plan for Day 3 (*continued*)

Time Allotted and 7e Model Stage(s)	Lesson Procedure: What Are the Students Doing?	Instructional Notes: What Is the Teacher Doing?	Physics Opportunities	Engineering Opportunities
15 mins. **Evaluate** **Explain**	• Student groups present their pendulums and songs to the class for evaluation.	• Use the rubric to score the metronome performance for each group. • The other parts of the rubric can be scored when engineering notebooks are evaluated.	—	• Students communicate their results to the class.
Extend	**Homework:** Students should complete the summary questions in their engineering notebook.			

Optional Modification and Extension (Extend)

- Modify part 1 by having each group test only one variable. For example, have one group test the effect of varying the length, another group test the effect of varying the mass, and so on, and then have the groups present their findings. This will reduce the time needed for part 1.
- Modify part 1 by assigning each group to test one specific length, one specific mass, and one specific angle (holding other variables constant) and then present their period results to the class. Then have the class collate the data and determine which variables affect the period of a pendulum.
- Modify part 2: From part 1 data, have groups create a graph of beats/minute (frequency of pendulum) versus length of pendulum. Then give students songs with known beats per minute. Students will use their graph to predict how long their pendulum must be to match the beat of the song. Then they can build the predicted pendulum and see how close they are to the actual pendulum metronome.
- Create a pendulum metronome that makes an audible click for each swing (much like an actual metronome).

Differentiated Instruction

Special Needs

- Provide students with a checklist of daily goals.

- Use preprinted engineering notebook templates for students who need the structure for documentation.
- Have preprinted blank data tables and graphs with the axes labeled for student use.
- Allow for different types of documentation such as using a computer to type or for students who might struggle with a handwritten engineering notebook, using phones or tablets to take pictures and then add captions.

English Language Learners

- Have visuals around the classroom for terms such as *engineering design process, period*, and *frequency*.
- Provide sentence frames and use technologies for students to record in their engineering notebook.

Supplemental Material

- Handout 8A: Pendulums—And the Beat Goes On

HANDOUT 8A: PENDULUMS—AND THE BEAT GOES ON

DIRECTIONS

You are part of a team of engineers who are building a metronome (a device that helps musicians keep time). One type of metronome is a pendulum, which is a simple device that consists of a length of string or wire, a bob or some other type of weight, and a fixed point where at which it is attached to a solid object. The pendulum may swing in various directions.

OBJECTIVES

Your goal is to build a pendulum that works as a metronome to keep pace with the beat of a song. You will investigate the properties of pendulums and use this information to inform your design.

MATERIALS

- Strings
- Various masses
- Protractor for measuring angle
- Meter stick
- Rings and ring stands
- Scissors
- Safety glasses or goggles

SAFETY PRECAUTIONS

- Follow all general lab safety procedures.
- Wear personal protective equipment (eye protection) during the setup, hands-on, and takedown segments of the activity.
- Use caution in working with sharps (scissors), which can cut or puncture skin.
- Keep your feet free of swinging masses in an oscillation pattern to avoid injury.

- Make sure objects are removed from the path of the oscillation pattern.
- Wash your hands with soap and water upon completing this activity.

PART 1: INVESTIGATING PROPERTIES OF PENDULUMS (1–2 DAYS)

Complete experiments to determine how length, mass, and angle of a pendulum affect the period of the pendulum. For each variable, gather enough data to be able to provide sufficient evidence (in graph form) for how that variable affects the pendulum's swing time. For each trial, record the time it takes to complete 10 swings and then calculate the period and frequency for each trial. Put all data into well organized and labeled data tables in your engineering notebook and graph the data to show the variable's effect on the swing time. Graphs should be inserted into the engineering notebook at an appropriate location.

After presenting your data results to the class and viewing all of the class's data, answer the following questions in your engineering notebook:

- From the class data, which factor(s) are consistently seen to affect the period of a pendulum?
- Which ones either don't affect or don't consistently affect the period of the pendulum? Use evidence to support your answers.

PART 2: BUILDING AND PRESENTING A METRONOME (1 DAY)

Locate a song and construct a pendulum that keeps the beat with the that song. You will present the pendulum and song to the class, along with a calculation of the tempo of the song (beats per minute). The pendulum should keep pace with the song for at least 10 swings.

POST-ACTIVITY QUESTIONS

Summarize your findings about what which variables greatly significantly affect the period of a pendulum.

1. How did your results from part 1 help guide your thinking in part 2 of this project?

2. How successful was your pendulum at keeping the beat to a song? Explain the success (or lack of success).

Assessment Rubric

Element	Excellent (5 points)	Good (4 points)	Fair (3 points)	Poor (1 point)
Data collection and calculations	All calculations and units are correct.	Most calculations and units are correct.	Some calculations and units are correct.	Few or no calculations or units are correct.
Graphs	Graphs are accurately plotted, have their axes labeled, and show correct units.	Graphs contain most elements listed in Excellent column.	Graphs contain some elements listed in Excellent column.	Graphs contain few or no elements listed in Excellent column.
Question Responses to questions	All questions are answered with exceptional clarity and detail.	All questions are answered clearly and in detail.	Answers are somewhat clear or detailed.	Answers lacking in clarity or detail.
Metronome performance	• Metronome keeps perfect time for 30 seconds.	• Metronome is very close to correct tempo after 30 seconds.	• Metronome is somewhat close to correct tempo after 30 seconds.	• Metronome is not close to correct tempo.

TOTAL ______ / 20

ACTIVITY 8B: GUITAR DESIGNS–EXPLORING HOW MUSIC IS MADE

Contributors: Julie Mills and Jon Kelley

Time frame: 2 class periods plus additional time outside of class

Physics focus: Sound, waves, harmonics, vibrations, resonance, standing waves, and frequency

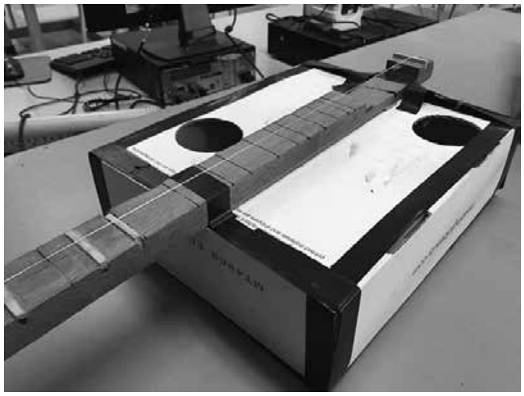
Engineering focus: Design, analysis, models, and communication

Opportunities for Science Versus Engineering Concepts

Concept	Science	Engineering
Design	• No experimental design • Location of the frets	• Designing a functional guitar • Reverse engineering
Analysis	• One octave higher is a doubling of the frequency. The notes within the octave have a mathematical relationship as well.	• Analysis of materials for strength, resonance, (materials testing) • Analysis resonator for sound quality.
Models	• Wave model • Standing wave	• Physical model (building the guitar)
Systems	• String, tension, and the strength of the post each can be isolated to understand the physics of each component.	• Resonator system, vibration system, post system

PROJECT OVERVIEW

Many students have a general understanding of how sound is created, but even those who play instruments don't really understand the how and why of different pitches and how it all fits together to make a pleasing sound. The goal of this activity was to create a design project that required students to explore the relationship between vibrations, pitch, and resonance at a deeper level than what is addressed in class. This design engineering project is completed toward the end of a unit on waves. Within the unit on waves, the ideas of sound and vibrations, frequency, standing waves, and resonance are discussed and demonstrated.



Sample cavity designed by students using a small box, with neck of the guitar over the resonating cavity and offset holes

To get students interested in this project, begin the activity by showing a video of children who make instruments from trash and then play those instruments in an orchestra setting (*www.youtube.com/watch?v=sJxxdQox7n0*). This video engages students and provides an anchor to introduce the project of creating guitars from recycled materials. Within the same class period, students work in small groups exploring the parts and design of a real guitar, the purpose of each part, and how the parts fit together. The groups report their results to the class and the class makes a comprehensive list for all to see. Afterward, students are given the constraints and requirements for this particular design project, with extra emphasis on the resonating cavity and string analysis requirement.

Because this activity is completed outside the classroom, it is important to spend time reiterating the process that should be followed and the purpose and requirements of the engineering notebook. Also, working on the project outside of class time gives students the option of working alone or with one or two other partners, with the understanding that all partners need to be present during the design and build process. Furthermore, it is ideal to make the classroom available during the day and after school for college preparatory and honors physics students who face obstacles getting together outside of the school day.

Students complete this project mostly on their own, so the teacher does not typically provide building materials for the students,[1] but he or she may make a variety of string types available (e.g., yarn, thread, kite string, twine, fishing line) for students to analyze in the classroom; then students can take home pieces of the strings they want to use for their guitars. The students analyze a string's performance by stretching a piece of it over an open box and plucking it to observe the sound made.

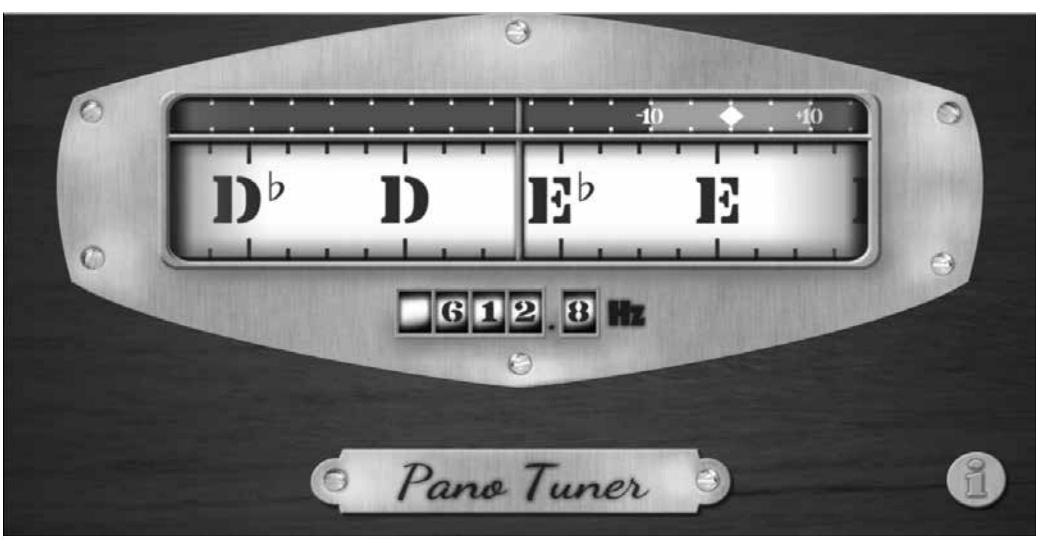
In addition to strings, the teacher may provide a variety of containers (different sizes and made of different materials) for students to analyze the resonating ability so that they can make informed design decisions. Analysis of resonating cavities can be performed by holding the base of a ringing tuning fork or their vibrating smartphone (the

1 The contributing teachers also do this project in a conceptual physics course, but in that context, the bulk of the designing and building is completed in class (about four additional class days). Students complete the string analysis and resonating cavity analysis in the classroom and then are provided with a variety of materials to complete the build in class.

app Real Razor works well for this) on the container and observing how much the sound is amplified. The analysis of string types and resonating cavity performance can also be performed at home. All observations must be recorded in students' engineering notebooks. When you're closer to the due date, spend about one half of a class period showing students how to mark the frets on their guitars so they get a perfect octave of notes. It is best to demonstrate this process on a sample homemade guitar that you can save and use year to year. Because students need to know the frequency of the notes played when the string is plucked, it is imperative that they have access to a tuning device that can detect and display the pitch (frequency in Hertz) and name (e.g., A, D, G,).

Fortunately, a variety of free smartphone apps for this are available (e.g., the Pano Tuner app). A handout showing the different notes of an octave is used as a guide. Individual help is provided to students after school if they are still struggling with marking their fret markings. Frets can be marked with a pencil or marker, or can be made more pronounced by gluing a small piece of wood at the fret location. One minor difference between how a real guitar is played and these homemade guitars is that, on a real guitar, the finger positions will be between frets, whereas on their guitar, the finger positions will be on the actual fret locations. This change is made to make it easier for students to play the guitar, as many of them do not play actual guitar.

Guitars are presented in class during one class period. Each student group presents its guitar, giving a short explanation of reasoning for its design choices. Then one of the students in the group will play a short song on the guitar. Song choices are discussed



Pano Tuner app showing both the frequency of the sound and the name of the note. As students adjust their finger position along the neck of the guitar, this app tells them when they reach the desired frequency and note.

ahead of time (a list of possible songs are provided, but groups can choose other songs with teacher approval). The song must use a wide variety of notes (finger placements). In addition to the class presentations by the groups, each student must turn in his or her engineering notebook for assessment and each group must turn in a guitar design report for assessment.

BIG IDEAS

- **Physics:** Sounds are made from vibrations. Resonators amplify the sound. Some materials are better resonators than others. Standing waves created on strings can be altered by both the tension and the length of the string, affecting the pitch or frequency of the sound produced. All musical instruments create an amplified sound through standing waves and resonating cavities.
- **Engineering:** Collecting and analyzing the right data is integral to making informed design decisions. Each part of a system plays a role in the functioning of that system and affects the system's performance as a whole.

Connections to the *Next Generation Science Standards*

Performance Expectation

- HS-PS3-3: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

Science and Engineering Practices

- Asking questions and defining problems
- Developing and using models
- Analyzing and interpreting data
- Constructing explanations and designing solutions
- Obtaining, evaluating, and communicating information

Disciplinary Core Ideas

- PS3.A: Definitions of Energy
- PS3.D: Energy in Chemical Processes and Everyday Life
- ETS1.A: Defining and Delimiting Engineering Problems

Crosscutting Concepts

- Cause and effect

- Systems and system models
- Structure and function

Assessment: Determining Acceptable Evidence

Formative

- Small group and class discussion of the parts of a guitar and their functions
- Quick check of collected data for string and resonating-cavity performance

Summative

- Individual: engineering notebook
- Group: presentation of guitar and performance with it, group report

Materials and Preparation

- Safety glasses or goggles for each student
- Several real guitars for groups to observe form and function
- Variety of string types (twine, kite string, fishing line, thread, yarn, and so on)
- Open boxes (any size will work)
- Smartphone with tuning app
- Engineering notebooks for each student
- Handouts for each student
- Method for showing a YouTube video to students as a class
- Optional: containers made of a variety of materials (e.g., plastic, glass, cardboard)
- Optional: tuning forks

Safety

- Wear personal protective equipment (eye protection) during the setup, hands-on, and takedown segments of the activity.

Guitar Design Project Lesson Plan for Day 1 (50-minute block)

Time Allotted and 7e Model Stage(s)	Lesson Procedure: What Are the Students Doing?	Instructional Notes: What Is the Teacher Doing?	Physics Opportunities	Engineering Opportunities
12 mins. **Engage**	• Introduce the project by showing the YouTube video "Landfill Harmonic Amazing and Inspirational."	• The YouTube video engages students by presenting a real-world example of how instruments can be made from recycled materials.	—	—
15 mins. **Elicit** **Explore**	• Work in small groups to explore the parts and function of an actual guitar. On one sheet of paper per group, sketch the guitar and label its important parts and their functions (or just list the parts and functions).	• While groups are revealing their prior knowledge about instruments and exploring actual guitars to determine the important parts and their functions, go through the room to answer questions and encourage groups to go beyond the most obvious parts and functions. Important parts include the resonating cavity (with holes), bridge (to raise the strings so that the full string vibrates), strings, frets, neck, and tuning keys (mechanism to change string tension).	• Exploring examples of resonance, vibration, frequency, and pitch	• Systems thinking and how system parts fit together to make the whole • Explaining the function of various parts of an object • Identifying design constraints based on type of instrument
5 mins. **Explain** **Evaluate**	• Each group presents part of its findings. • Create a comprehensive list of findings and diagram on the board.	• Cycles through groups, having each group present a portion of its findings. • Creates a comprehensive list of features and diagram on the board.	—	—

Guitar Design Project Lesson Plan for Day 1 (*continued*)

Time Allotted and 7e Model Stage(s)	Lesson Procedure What Are the Students Doing?	Instructional Notes What Is the Teacher Doing?	Physics Opportunities	Engineering Opportunities
20 mins. **Explain**	• Read through the project expectations and rubric handout as the teacher explains the project. • Write the introductory page of their engineering notebooks.	• Read through (orally) the comprehensive list and clarify parts and misconceptions. • Demonstrate analysis methods for testing resonators and strings.	—	• Goals • Constraints

Guitar Design Project Lesson Plan for Day 2–How to Mark the Frets to Play an Octave (30-minute block)

Time Allotted and 7e Model Stage(s)	Lesson Procedure: What Are the Students Doing?	Instructional Notes: What Is the Teacher Doing?	Physics Opportunities	Engineering Opportunities
5 mins. **Elicit**	• After listening to the teacher play eight random notes from low to high and then an octave of notes from low to high students describe their thoughts about the two sets of notes. Is one more pleasant sounding then another? • Describe the spacing of the frets on a real guitar or homemade guitar, noting how the spacing varies as you move up the neck of the guitar.	• Post prompting questions • Ask, "What makes a pleasant sounding set of notes, versus an unpleasant one? • Ask, "How are the frets on a guitar spaced? What determines where the frets are marked on a guitar?" • On a real or homemade guitar, play eight random notes from low to high and then eight notes in an octave from low to high so that students can hear the difference. • Students should have access to a few guitars to play and look at fret spacing.	• Pitch and frequency • String vibration • Standing waves on string	• Materials, analysis selection versus design • Application and constraints

Guitar Design Project Lesson Plan for Day 2—How to Mark the Frets to Play an Octave (*continued*)

Time Allotted and 7e Model Stage(s)	Lesson Procedure: What Are the Students Doing?	Instructional Notes: What Is the Teacher Doing?	Physics Opportunities	Engineering Opportunities
5 mins. **Elaborate** **Explain**	• As a class, discuss the difference between the random eight notes and the octave notes in terms of pleasantness of sound.	• Briefly explain frequency's role in creating the notes of an octave so students learn to recognize the difference between eight random notes and the eight notes of an octave (i.e., where the lowest note is twice the frequency of the highest note).	• Frequency • Standing wave	• Students consider the client aspect of the design and think about sound quality. • Students begin to consider materials for the design project.
20 mins. **Explore**	• Watch the teacher demonstration of the Pano Tuner app (or similar app). • Refer to the student handout "Setting Up Your Guitar to Play a Full Octave," which lists all of the notes of an octave given the first note of the octave.	• Demonstrate how the Pano Tuner app works. • Demonstrate the fret-marking process. • Explain to students that it typically is easiest to start with one string by plucking the open string (no fingers holding the string down). Once the open string note has been identified by the app, they can use the handout as a reference for determining the remaining seven notes of that octave. Adjusting the tension in the string can vary the frequency of the open string. • By moving the finger that presses on the string down the neck of a guitar, students can locate the place where the string should be held to create the next note in the octave. Mark this fret location on the neck (pencil, pen, or marker works well).	• Frequency • Resonance • Frequency versus wavelength relationship	• Students analyze an existing product and use that as a model for their own design.

Guitar Design Project Lesson Plan for Day 2—How to Mark the Frets to Play an Octave (*continued*)

Time Allotted and 7e Model Stage(s)	Lesson Procedure: What Are the Students Doing?	Instructional Notes: What Is the Teacher Doing?	Physics Opportunities	Engineering Opportunities
20 mins. **Explore (*continued*)**		• Repeat the process until the all eight notes of the octave have been marked and identified. At this point there will be seven frets marked. • Optional extension: Have students calculate the length for notes using mathematical analysis. • This fret location will be the same for all of the strings on the guitar, but students should understand that each string would play a different octave depending on the tension in the string and the type of string. For this reason, it is easier to stick with making a one-string guitar.		

Guitar Design Project Lesson Plan for Day 3–Presentation Day (20-minute block)

Time Allotted and 7e Model Stage(s)	Lesson Procedure: What Are the Students Doing?	Instructional Notes: What Is the Teacher Doing?	Physics Opportunities	Engineering Opportunities
20 min **Explain Evaluate**	• Student groups present their guitars to the class whole-class presentation). Presentation includes a brief overview of students' design choices and reasoning, playing of the octave, and playing of a song. • When not presenting, students can be rating other groups' guitars on their sound quality and guitar structure. • After the presentations, if time remains, put the guitars on display for others to see up close and try out.	• Use the rubrics to score presentations and ask guiding and extending questions.	—	• Students can develop a class rating system to evaluate products. This is a chance for everyone to examine different constraints and design criteria.

Optional Modification and Extension (Extend)

- It is possible to complete this entire project in the classroom (about five additional days are needed). Students would complete the resonator analysis and string analysis in the classroom and then design and build their guitar, demonstrating how the results of their analyses guided their design choices. When done in class, ask students to bring in their own materials for resonators and guitar necks (although we suggest having some set aside for students who need them); the teacher typically provides the string.
- Have students calculate the speed of sound in their guitar string(s) using the frequency of the note of the open string (first harmonic) and the length of the string being played. (The first harmonic length is one half of the wavelength.) By repeating this calculation for several fret positions, an average speed of sound can be determined.
- It is helpful to have checkpoints along the way to the final due date with any out-of-class engineering project. Checkpoints usually involve having students show

what they have done so far (either by bringing in their guitar or showing pictures of it) and show entries in their engineering notebook of resonator and string analysis data.

Differentiated Instruction

Special Needs

- Provide students with a checklist of daily goals.
- Use preprinted engineering notebook templates for students who need the structure for documentation.
- For students who might struggle with a handwritten engineering notebook, allow different types of documentation such as using a computer to type or phones or tablets to take pictures and then add captions.

English Language Learners

- Have visuals around the classroom for terms such as *engineering design process, frequency, resonator,* and *vibrations.*
- Provide sentence frames and use technologies for students to record in their engineering notebook.

Supplemental Materials

- Handout 8B-1: Guitar Design Project Expectations and Rubrics
- Handout 8B-2: Setting Up Your Guitar to Play a Full Octave
- YouTube video: "Landfill Harmonic Amazing and Inspirational," *www.youtube.com/watch?v=sJxxdQox7n0*

HANDOUT 8B-1: GUITAR DESIGN PROJECT EXPECTATIONS AND RUBRICS

PROBLEM

- To build a guitar using recycled, reused materials that meets the listed constraints
- To present the guitar to the class and play an octave and a song using the guitar

DUE DATES

- Presentation of guitar in class: ____________________________________
- Final report: ____

CONSTRAINTS

- No parts or pieces can be from a real guitar.
- The guitar must be constructed out of recycled and re-purposed materials.
- The guitar must be clearly audible across the classroom.
- The guitar must be tunable (i.e., have a string or strings that can be tightened and loosened).
- The guitar must have frets marked so that a full octave can be played.
- The guitar must contain a resonating cavity.
- The guitar must be robust enough to be played multiple times.

SAFETY PRECAUTION

Wear personal protective equipment (eye protection) during the setup, hands-on, and takedown segments of the activity.

PROCESS

This project will be completed outside of class time. At the beginning of the project, it is expected that time will be spent brainstorming and trying out different ideas before finalizing and implementing a plan. *Enter all aspects of the design process in your engineering notebook, using the format at the back of the notebook.*

Make special note of the following aspects of your guitar design:

1. The design process you followed to get from the initial problem to the final solution (i.e., your brainstorming and sketches of initial ideas → your analysis of materials to choose the best ones → your building, testing, and redesign → the marking of the frets for playing an octave → the final result)
2. The analysis of the guitar's parts, pieces, and aspects to optimize the guitar to meet the constraints
3. How the various parts and pieces of the guitar were put together as a system to make the final product

If you need help on any aspect of this project, don't hesitate to ask the teacher. If you are lacking materials, see the teacher. If you need help with the tuning portion or marking the frets to play an octave, bring the guitar in to school before the day it is due so that the teacher can help you.

PRESENTATION

To present your guitar to the class, you will be asked to play through the entire octave correctly and then to play a simple song. Some examples of simple songs are "Twinkle, Twinkle, Little Star," "Happy Birthday," and "Joy to the World"; however, you can choose another song, as long it uses most of the octave's notes and you get the teacher's approval ahead of time.

GRADING

The grading for this project uses multiple rubrics. You will be graded on the final guitar, on your group's presentation, on your engineering design notebook (individual grade), and on your final report.

FINAL REPORT

A final report (one per group) should be typed and submitted and should include the following items:

- **Heading:** Title, date, group members' names
- **Materials:** A list of materials that you used to build your guitar
- **Final Design Sketch:** A sketch of the final design of the guitar. It can be hand-drawn on the typed report, created by computer, or drawn and then scanned and inserted.
- **Build Process:** An explanation of the build process your group followed to build the guitar

- **Pictures:** Pictures of the guitar during the build process (can be jpegs inserted into the final report), with annotations for each picture. The pictures can be included within the "Build Process" section of the report separate after that section.
- **Analysis:** A summary of analysis that was done on parts and pieces of the guitar to gather data to make more informed design choices
- **Reflection:** A reflection about the project, including a discussion of how and why your final completed guitar differed from your original, brainstormed design. Also, within your reflection, include a discussion of difficulties your group encountered in the design and build process and how the group was able to overcome those difficulties.
- **Changes:** A discussion of changes your group would make if you had to build another guitar or to redo this project and why your group would want to make those specific changes.

Group members: ____

Rubric for Completed Guitar and Presentation

Constraint Details	4	3	2	1	0
Completed guitar met all constraints ____ / 12 (add at bottom)					
Use of recycled materials but not real guitar parts • No part of the guitar is from an actual guitar. • You successfully and creatively used recycled and repurposed materials in creating the guitar.					
Strings and frets • Frets are marked on the neck in the correct locations for playing an octave. • String choice gives the guitar a nice sound.					
Resonating cavity • Resonating cavity is designed to give nice resonance, making guitar easily heard.					
Playability of guitar • Guitar is easily played. • Playability was clearly taken into account when designing the guitar. • Strings have an easy way to tune them.					
Sound of guitar • Guitar is easily heard across the classroom, even when noisy. • Guitar has a pleasant sound					
Song played • Choice is creative. • Song is recognizable. • Song uses most of the notes of the octave.					
Octave played • Octave is correct and easily played.					

Points for constraint details: ______________________________

Points from above for meeting constraints: ____________________

TOTAL SCORE ______ / 40

Group members: ____

Rubric for Guitar Project Final Report

Element Graded	Base Points 4	3	2	1	Point Calculation	Total Points
Materials • Materials list includes all materials used AND all tools used.					× 1 =	
Final design sketch • Detailed sketches (several if needed) including labels of parts/ materials used on the sketch • Dimensions are included on the sketch					× 2 =	
Build process • Complete and thorough description of entire build process from beginning to end (can be step-by-step or paragraph form)					× 2 =	
Pictures • A variety of pictures (easy to see) are included from the entire build process and pictures are annotated					× 2 =	
Analysis • More than one analysis process is described, including what was done during the analysis, what was being tested, the results of the analysis, and how the results helped inform design decisions					× 2 =	

Rubric for Guitar Project Final Report (*continued*)

Element Graded	Base Points				Point Calculation	Total Points
	4	3	2	1		
Reflection • Detailed discussion of how and why your final completed guitar differed from your original brainstormed design. • Difficulties your group encountered in the design and build process and how the group was able to overcome those difficulties.					×2 =	
Changes • Detailed discussion of several changes your group would make if you had to build another guitar or to redo this project • Reasoning provided for why your group would want to make those specific changes.					×2 =	

REPORT TOTAL ______ / 52

Name: ____

Rubric for Engineering Design Notebook (Individual Grade)

Graded Element	Details	Points
Daily Log Format	• Dates, group members in attendance, signature at end, neat layout	__________ /10
Level of Detail	• Detailed entries including notes/thoughts and reflections (can be seen on multiple occasions)	__________ /15
Data and Analysis	• Data collected in neat format so that it is easily understood, can be seen on multiple occasions • Each time data is collected, claims are made (What can you tell from the data collected and what evidence do you have to show this?) • Analysis of data included, summarized, and explained each time data is collected	__________ /15
Sketches	• Sketches are included throughout the process (multiple occasions) and are annotated/labeled • Sketches include initial brainstorming ideas, along-the-way sketches, and final designs	__________ /10
Notes	• Meaningful notes are taken throughout the process • Notes include personal reflections and thoughts about the process. • Notes include what you completed and what you are planning on completing at the next group meeting.	__________ /15

TOTAL ______ / 65

HANDOUT 8B-2: SETTING UP YOUR GUITAR TO PLAY A FULL OCTAVE

An *octave* is a series of eight notes whose frequencies vary in such a way that the lowest note of the octave has a frequency that one half as much as the highest note of the octave. Here is a chart of all of the notes on a piano and their frequencies:

Note	Hz	Note	Hz	Note	Hz	Note	Hz	Note	Hz	Note
C1	32.7	C2	65.4	C3	130.8	C4	261.6	C5	523.3	C6
C#1	34.6	C#2	69.3	C#3	138.6	C#4	277.2	C#5	554.4	C#6
D1	36.7	D2	73.4	D3	146.8	D4	293.7	D5	587.3	D6
D#1	38.9	D#2	77.8	D#3	155.6	D#4	311.1	D#5	622.3	D#6
E1	41.2	E2	82.4	E3	164.8	E4	329.6	E5	659.3	E6
F1	43.7	F2	87.3	F3	174.6	F4	349.2	F5	698.5	F6
F#1	46.2	F#2	92.5	F#3	185.0	F#4	370.0	F#5	740.0	F#6
G1	49.0	G2	98.0	G3	196.0	G4	392.0	G5	784.0	G6
G#1	51.9	G#2	103.8	G#3	207.7	G#4	415.3	G#5	830.6	G#6
A1	55.0	A2	110.0	A3	220.0	A4	440.0	A5	880.0	A6
A#1	58.3	A#2	116.5	A#3	233.1	A#4	466.2	A#5	932.3	A#6
B1	61.7	B2	123.5	B3	246.9	B4	493.9	B5	987.8	B6

Notes and Frequencies Chart

The Major Scale

Key	C	C#	D	D#	E	F	F#	G	G#	A	A#	B	C
C	1		2		3	4		5		6		7	1
D		7	1		2		3	4		5		6	
E		6		7	1		2		3	4		5	
F	5		6		7	1		2		3	4		5
G	4		5		6		7	1		2		3	4
A		3	4		5		6		7	1		2	
B		2		3	4		5		6		7	1	

On a guitar, the frets mark where to place your fingers so that as you move them down the neck, you can play a full octave of notes on one string. On a real guitar, the finger is placed between two frets, but for the purposes of this project guitar, you can just mark the frets where you actually need to place your finger.

To set up your guitar to be able to play an octave, do the following:

1. Get a tuner app (such as the Pano Tuner app) to know what note you're playing and its frequency.

2. Pluck the open string on your guitar. Determine what note it is played and tune the string so that it will play the starting note of any major scale keys shown in the major scale chart. This will tell you what major scale octave your string will play after you mark the frets.

3. Once you know your starting note (denoted by a 1 on the major scale chart), determine what frequencies you will need to locate for notes 2–8 (the rest of the octave).

4. Move your finger along the string, pressing on the string and plucking the string until you can locate the frequency for note 2 on your octave. When you find it, mark it on your guitar.

5. Repeat step 4 for each remaining note until you have seven frets marked (for notes 2–8). The open string is note 1.

Index

Page numbers in **boldface** type refer to figures, tables, or images.

Infusing Engineering Into High School Physics

How can we interweave opportunities to learn engineering concepts and skills in an already-packed science curriculum? That was the problem that 30 Boston-area high school physics teachers aimed to solve when they took part in Project Infuse, a National Science Foundation study. Discover their practical solutions in this book, *Beyond the Egg Drop*, which is designed to enable physics teachers to expose students to engineering as they teach physics.

Beyond the Egg Drop is a user-friendly resource that does the following:

- Answers the *Next Generation Science Standards' (NGSS's)* call to add an engineering focus to your lessons so students can take part in authentic STEM experiences.
- Provides a thorough discussion on the rationale, justification, meaning, and implementation of integrating engineering into your science curriculum.
- Offers 24 engineering-infused physics lessons that include examples of student work; cover assessment, teaching, and student learning; and connect to the major content areas of physics, *A Framework for K–12 Science Education,* and the *NGSS*.
- Covers mechanics, optics, electricity, and thermodynamics in lively lessons with engaging titles such as "Bungee Jumping Cord Design" and "Lights Out! Zombie Apocalypse Flashlight."

And here's another problem-solving feature you're bound to appreciate: The lessons vary in length, so you can use them to fit the needs of your own classes. Some require part of a class period; others can take days or weeks. Some are activators that are best used before any discussion of physics principles; others work as capstones. All of the lessons are teacher-tested, so you can be sure they'll include engineering concepts and skills without making you restructure your existing physics curriculum.

PB432X
ISBN: 978-1-68140-035-8

Grades 9–12

NSTA press
National Science Teachers Association

9 781681 400358