#SeaworthySTEM

Harmonious Waves

Crafting Musical Instruments through Physics

Grades 9-12

Teacher Guide

Seaworthy STEM™ in a Box Series

Harmonious Waves!

Crafting Musical Instruments through Physics

Teacher Guide for 9-12

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Seaworthy STEM™ in a Box Educator Kit description:

Seaworthy STEM™ in a Box activities are a Navy initiative to provide enhanced Naval-relevant, standards aligned, hands-on activities to K-12 teachers and students. Components of this program include, curated sets of classroom activities that aim to build deep conceptual understanding in Naval-relevant content areas. The kits also includes comprehensive lesson plans, material lists, scientific background information, STEM related literacy books, and student activity sheets. The Seaworthy STEM™ in a Box program is designed to support teachers as they select content, acquire materials, and implement more hands-on STEM activities in their classrooms. Increasing student access to hands-on STEM activities, also increases awareness of STEM career paths, engage students in STEM, and support development of student's abilities in STEM content.

The Seaworthy STEM™ in a Box kits were designed to guide students through the scientific inquiry-based theory and the engineering design process. The content and Naval-relevant activities are aligned with the Next Generation Science Standards. The topics and content covered within the lessons are connected and scaffolded based on distinct grade bands (K-2nd, 3rd-5th, 6th-8th, and 9th-12th).

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Introduction

Welcome to an innovative curriculum designed to engage students in the world of engineering, problem-solving, and creative thinking. This curriculum is structured around three fundamental components, each carefully crafted to provide students with a comprehensive learning experience. In this curriculum, each lesson is divided into three parts: Journal Entry, Part 1, and Part 2.

Parts of Each Lesson

Journal Entry

The first part of every lesson serves as a bridge between what students already know and what they are about to learn. The Journal Entry is an opportunity for students to reflect on their prior knowledge and experiences related to the topic. These questions will stimulate critical thinking and prime students for the exploration of new concepts. The teacher can mold these questions into a format that best fits their class. This entries can be done in the student workbook, a separate journal notebook or another location determined by the educator.

Part 1: Introduction & Research

Following the Journal Entry, Part 1 of each lesson is dedicated to research and in-depth exploration. The students will delve into the subject matter, investigate key concepts, and gather valuable information. This phase is essential in providing the foundation for the Engineering Design Challenge, ensuring that students have the necessary background knowledge and skills to approach real-world problems effectively. Do not feel as though you have to strictly follow these instructions. Use the tools that are necessary for your students. This could include adding teaching strategies, word banks or other differentiation techniques to the lessons.

Part 2: Engineering Design Challenge

The culmination of each lesson is the Engineering Design Challenge. This is where students put their newfound knowledge and research skills to the test. They will work through the engineering design process, applying their problem-solving abilities to develop practical solutions. The challenges are crafted to mimic real-world scenarios, allowing students to experience the fulfillment of creatively designing their own products. Engineering education can be enriched by infusing elements of business-style competitions into your lessons. This approach not only deepens students' technical understanding but also hones their teamwork, critical thinking, and real-world problem-solving skills. This can be done by using the team dynamics page as a "business" team page. Remember, as the teacher you create your materials pricing list from what you have. This will allow you to have more control over the outcome of the lesson. The educator becomes the customer while the students incorporate regular pitch sessions as part of the final presentation. Play with the style of the lesson and build students up to feel the business dynamic that unfolds through the engineering process.

Here We Go!

By the end of this curriculum, students will have the tools and confidence to address real-world challenges in a systematic way. This curriculum is designed to provide the basics and help organize a young engineers thought patterns. Teaching students how to map out their thinking is essential in the development of world changing solutions. We are excited to embark on this educational journey with you! Let's get ready to journal, research, and create as we embark on a #SeaWorthySTEM learning adventure!

Table of Contents

Lesson Title:

Harmonious Waves

Crafting Musical Instruments through Physics

Time:

Average learning time is 4-5, 50 minute class periods

Student Objectives:

1. Apply the engineering design process to construct a functional and efficient instrument by applying knowledge of wave properties and their effects on sound production.
2. Investigate the relationship between the physical characteristics of wave patterns and frequencies produced.
3. Analyze and interpret data collected during experimental trials.
4. Apply critical thinking and problem-solving skills to troubleshoot the design of the musical instrument, ensuring the efficient transfer of wave energy.
5. Collaborate with peers to solve real-world engineering challenges.

Lesson Overview:

In this high school engineering challenge, students will embark on an adventure to build their own #SeaWorthySTEM musical instrument using a limited set of materials. They will apply their knowledge of sound waves and frequencies to create a sound producing device.

Next Gen Science Standards (NGSS):

HS-PS4-1
Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

HS-PS4-2
Waves and their Applications in Technologies for Information Transfer
Evaluate questions about the advantages of using digital transmission and storage of information.

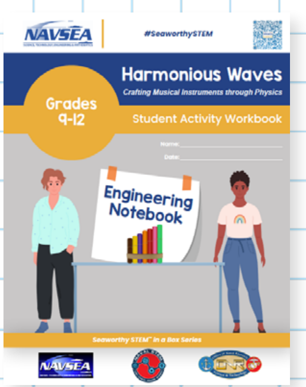
Notes

HS-PS4-5
Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

HS-ETS1-2
Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Materials and Equipment List

- 2m Schedule 40 PVC pipe
- Hacksaw or PVC pipe cutter tool
- Triple measure your 1/2" PVC prior to cutting
- 5 different colors of tape (one for each note)
- Sand paper or metal file
- Permanent markers
- Measuring device
- Electronic tuner or app



Student Activity Sheets/Handouts:

Student Activity Worksheet:
Harmonious Waves- Crafting Musical Instruments through Physics

Technology Tools:

Computer

Internet access

Part I: Background Research

1 Pre-Assessment Activity:

The student journal response can be used as a pre-assessment for this unit. Have the students answer these questions in the "Journal Entry" section of their engineering notebook.

Sample Journal Prompts:

1. What is the relationship between the frequency of a sound wave and the pitch of the corresponding sound?
2. How does the medium through which a sound wave travels affect the speed and propagation of the wave?
3. Can you explain the difference between transverse and longitudinal waves, providing examples of each?
4. What are the primary factors that contribute to the quality and timbre of a musical sound, and how are they related to the properties of the corresponding waves?
5. How do musical instruments utilize the principles of wave behavior to produce specific pitches and tones, and how does the design of the instrument influence the characteristics of the sound waves produced?

2 Pre-Activity:

Have the students answer these questions in the "Think about..." section of their engineering notebook. The teacher can post the questions below for the class to reference when answering.

Tell the students to "Think of a musical instrument or sound device structure" then answer the following questions:

1. How does sound travel through different mediums, and what role does the medium play in the speed of sound waves?

2. What are the key properties of a wave, and how do these properties manifest in the context of sound waves?

3. How does the frequency of a sound wave relate to the pitch of the corresponding sound we hear? Can this vary among individuals??

4. How do the principles of waves contribute to the beats and the formation of wave patterns in music?

YouTube:

3 Hook:

Show this video "CYMATICS: Science Vs. Music " and have students reference questions from the journal and pre-activity section: https://www.youtube.com/watch?v=Q3oItpVa9fs

4 Background Research- Primary Sources:

Research Artifacts:

- Have students complete the: "**Let's Explore Primary Sources & Research**"

5 Background Research- Information:

Research Sheets:

- Have the students complete the: "**Type of Instruments Research Sheets**"

6 Student Discussion:

After the students complete their research, use the information within both research sections to review with the students. Class discussions, share outs, partner shares or gallery walks are effective methods of communicating findings.

7 Engineering Design Challenge:

Discuss sound science by sharing Navy examples and explain the upcoming design engineering challenge. Some examples are included below:

1. **Sonar Systems:** The Navy uses sonar for

detecting and tracking underwater objects, such as submarines and torpedoes. Active sonar emits sound waves and analyzes the echoes that bounce back, This helps the Navy to locate and identify potential underwater threats.

2. **Communication:** Underwater communication systems allow the Navy to have contact with submarines and other underwater vessels. These communication systems use sound waves, such as low-frequency signals, to transmit messages, commands, and information over long distances.

Part 2: Engineering Design Challenge

Background Information:

The United States Navy uses acoustic systems to track and identify objects underneath the surface of the ocean. Submarines are built as an alternative to the surface vessels. Both passive and active acoustics are used to detect, locate and identify these potential threats.

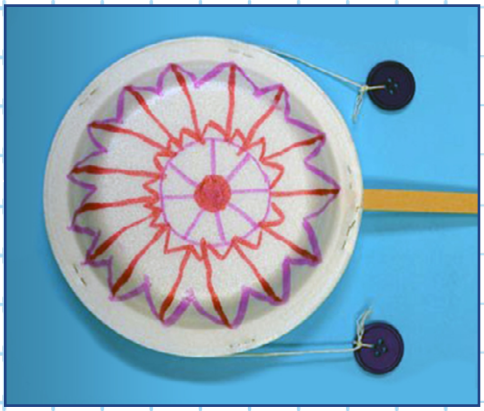
Submarines are machines that often possess a combination of components. As these connected pieces move as a system, they generate a unique set of vibrations that is commonly referred to as the "acoustic signature" of a vessel. The vibrations generate sounds which travel very well through the water. Using a passive collection tool like hydrophones or an active collection tool like SONAR to gather information allows acousticians aboard a naval vessel to use this signature to help identify the object.

Here is a link to a site to learn more about how the United States Navy uses acoustics: https://dosits.org/people-and-sound/national-defense/how-is-sound-used-to-find-submarines/

Musical instruments are manufactured to have their own unique signatures as well. In fact, many instruments have multiple components that are mathematically calibrated to generate a vibration which will in turn generate a wavelength at a certain frequency which will then produce a specific musical note.

Examples

Source: https://www.sciencebuddies.org/blog/sound-science-lessons



Source: https://letstalkscience.ca/educational-resources/lessons/design-build-a-musical-instrument

Source: https://pre-inscription.supmti.ac.ma/?a=20-diy-musical-instruments-for-kids-to-make-artsycraftsymom-gg-jK9aGLIN

The indigenous peoples of North and South America have been aware of these acoustic properties for thousands of years. Aerophones are a type of musical instrument that produce sound through the vibration of air. These instruments include flutes, whistles, reed instruments, and horns. Flutes and whistles are tubular or globular instruments with an edge against which the player blows to produce sound. Native American flutes and whistles come in various shapes and sizes and are made from a range of materials, including wood, bone, cane, clay, and bamboo. The number and position of finger holes, the specific design of the mouth hole, and the number of pipes involved are all features that differentiate different kinds of flutes. Reed instruments, such as clarinets, produce sound when the player blows air over a thin strip of cane or wood, causing it to vibrate. Horns produce sound when the player vibrates their lips against the mouth hole. Native American horns are often end-blown, have a cylindrical bore, and are made from materials such as bamboo, wood, bark, bone, clay, or calabash. They are used for signaling and ceremonial purposes.

Scientific-Mathematic Cheat Sheet

What does the math say?
It can be difficult to work with variables that you cannot see. Therefore, reviewing the information below will help you make decision before constructing your prototype:

The equation: $F = V/\lambda$

Frequency= Velocity divided by wavelength

Velocity= The speed of sound in the air ~330-345. It

is common for most people to use 343 m/s for room temperature air at 20 C.

λ= Wavelength (4 times the tube length measured in meters)

What does it all mean?
Why does λ= Wavelength (4 times the tube length measured in meters)? A pulse that starts in your hand as a compression makes 4 complete transits. One vibration = up and down as a rarefaction and up and down as a compression. This four-part cycle corresponds to one wavelength of a sound or a single vibration. A series of

these repeated cycles is the source of the sound you hear when you smack one of the pipes against the palm of your hand. Thus the frequency, or pitch of the tone depends on the length of the pipe. Sound waves are generated by air vibrating through the tube. The longer the length of the tube, the longer a wavelength the tube can accommodate, so the lower the frequency. Fewer vibrations per second will generate a lower note.

How does this happen?
When working with a cylinder the source (air) is set into vibration by hitting the end of it with the palm of your hand. The force will generate a variety of frequencies, but only one will persist. When at rest, your cylinder is an open tube and when it is played, it's a closed tube. A standing wave will be created in the closed tube when you strike it against your palm. The displaced air will vibrate throughout the tube oscillating parallel along the entire length. The air is not free to move past the closed end of the tube; it is known as a fixed point and acts as a node. Since the air is free to move out of the open end of the tube there are nearby spaces on the cylinders known as antinodes (The location of the antinode primarily depends on the diameter of the tube).

Video Resource:

https://youtu.be/bHdHaYNX4Tk

The Engineering Design Challenge:

The Navy has tasked your design team with creating a new musical instrument. Your craft must be able to produce the five intended sounds described below. The goal of your design is match the correct sounds using the tuner app to determine if your instrument was successful. Your team must be pay attention to detail and create a reasonable design to achieve this objective.

For this engineering design challenge, you are going to work with your team to first turn individual pieces of 3/4" PVC pipe into palm pipes which when played will generate a given musical note. After the individual pieces are tested and approved by your team, you will then modify and combine them into a pan pipe musical instrument that's capable of playing a wide range of notes!

A fun team activity is to have the same number of people in the team as there are notes in a particular song. (Ex. Row, Row, Row Your Boat contains 5 different notes, so that group should have 5 people). Have each student use the mathematical equation below to determine the length of their assigned note. They should then use the supplies to create a palm pipe of the appropriate length to play with the group. Once each person has created their own palm pipe and double checked their group member's work (Using the provided formula as well as a tuner) then the entire group will work together to play their song for the class. Use the chart as well as the items listed below to create 5 pipes that will each generate a different musical note: C1, D1, E1, F2 & G2.

Procedure:

Pre-Activity: Students will fill out a Team Dynamics page to review expectations and goals of the challenge.

1 What is the Problem?

- Have the students discuss the basic scientific principles associated with the lab: waves and frequencies.
- Introduce the engineering challenge:
    - ***Design and build a musical instrument that can make five specific sounds.***
- Form small teams and distribute the materials. Note: If allowing students to choose materials at random, create a materials home-base (a large box or storage container) designated for hand-selected materials.
- Have the students formulate a problem (in question form) from the scenario provided.

2 What are the Criteria and Constraints?

- Have the students list out the criteria and constraints for the lab.
- Constraints: Provide your students with a list of constraints for the engineering design challenge.

- Discuss budget constraints (a limited number of materials per team).
- Have the students fill out the budget form for their design.

  Possible ideas are listed below:

  - You will have (pre-determined number) of class periods to design, build and test your project.
  - Budget Constraints

3 How can we Brainstorm and construct the Prototype?

- Have the student brainstorm multiple designs for their prototype.
- Students will choose one design, justify their choice in the writing section and build their models according to their designs.
- Emphasize teamwork, creativity, and adherence to budget.
- Student construction tips:
  - Cut your pipe a little longer than measured to account for variables in the air, pipe, etc. This will allow the opportunity to fine tune your pipe by removing small amounts of length via filing and sanding.
  - Rounding the contact end (or the blowing end) of your PVC pipe using a file or sand paper will generally result in an instrument that generates notes on a more consistent basis.
  - Label each cut pipe with its frequency and corresponding note.

Number	Length (cm)	Note	Frequency (Hz)
1	23.60	F_1	349
2	21.00	G_1	392
3	18.75	A_1	440
4	18.50	Bb_1	446
5	15.80	C_1	523
6	14.10	D_1	587
7	12.50	E_1	659
8	11.80	F_2	698
9	10.50	G_2	784
10	9.40	A_2	880
11	9.20	Bb_2	892
12	7.90	C_2	1046
13	7.00	D_2	1174
14	6.26	E_2	1318
15	5.90	F_3	1397

4 **How can we Test and Data Collection?**

- Each team tests their prototype by:
  - A. Testing each of the five sounds against the tuner app.
  - B. Determine how you will collect data about your device (what determines a matching sound).
  - C. Record the trials for testing if the sound matches the note.

Note teachers are encouraged to have students create their own step-wise procedures as well. Students may develop different models then the ones listed above, allow for experimentation and flexibility in data collection.

5 What are our Findings? Data Analysis and Reflection

- Team present their findings by creating a data chart, graph and reflection statement to discuss the findings of their prototype.
- Teams discuss what worked and what did not in their design.
- Reflect on the engineering design process by answering the following questions:
  - A. Does my prototype meet the requirements of the design challenge?
  - B. Can I improve the design from its original specifications?
  - C. How can I reduce the cost of my final prototype without sacrificing quality?

6 Let's Improve it! Class Discussion, Team Redesign Conclusion

- Discuss the most successful designs and strategies.
- Relate the activity to real-world applications in naval engineering and design.

7 Peer Evaluation of Teamwork

- Students will be providing feedback of teammates and collaboration.

Teacher Background Information / Notes:

Waves and frequencies are fundamental concepts in understanding various phenomena in our world. Waves are disturbances that transfer energy from one place to another without transferring matter. They come in different types, such as sound waves, water waves, and light waves. Frequency, on the other hand, refers to the number of wave cycles that occur in a given time period. It is commonly measured in hertz (Hz) and is directly related to the pitch of a sound or the color of light. Higher frequencies correspond to higher pitches or brighter colors, while lower frequencies are associated with lower pitches or darker colors. Understanding waves and frequencies is crucial in comprehending how we perceive and interact with the sounds and sights around us, from the music we enjoy to the way we communicate using various technologies.

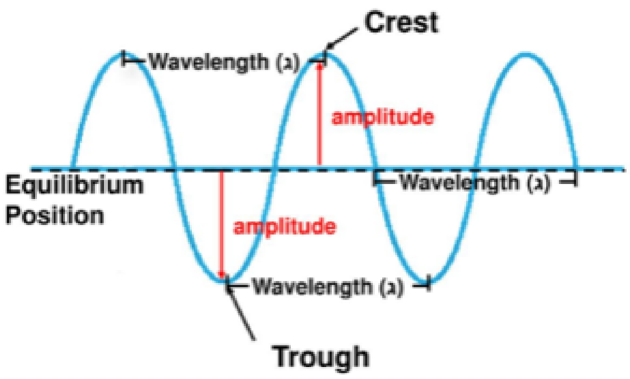
Optional Demonstrations to help with non-visual concepts: Introductory Demonstrations:

1. Fill a glass container (Allows for greater visibility). Drop a bead, penny, etc then watch the wave. Discuss how sound is a form of energy that radiates out in all directions in the form of a wave.

   Ask the class: Why do sound waves travel faster through water than air?

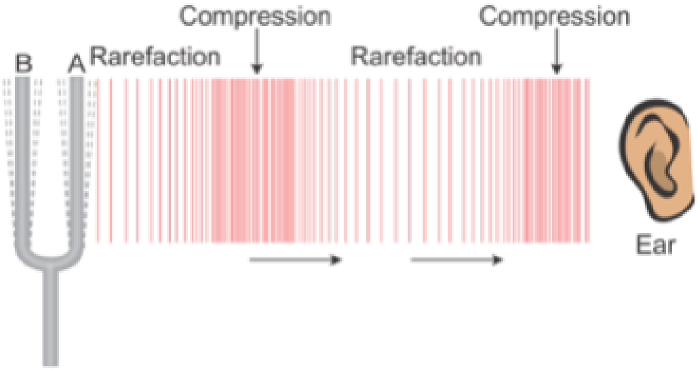
   Possible Discussion Factors:

   - Water: Density, Salinity, Temperature and Pressure
   - Air: Temperature, Air Pressure, Air Direction, and Humidity
   - Discuss parts of a wave (Diagram Below)

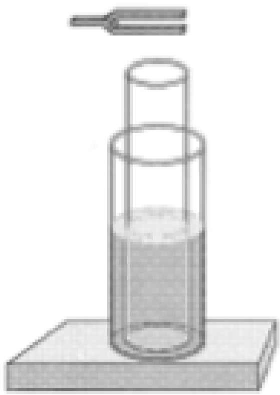


2. Tap at least two different tuning forks to open a discussion about how different frequencies are generated.

   Use this example to explain that compression is the high pressure part of a sound wave and rarefaction is the low pressure part of a sound wave and that the SI (International System of Units) unit for frequency is given in hertz which is determined by vibrations per second. Share with the students that the speed of sound through the air is ~330-345 m/s with the primary determining variable being the temperature of the air. *When it comes to air, humidity and temperature both play a role in the speed of sound. Humidity lowers the density of air, which makes it travel slightly faster. Heat makes air molecules move around faster, so they are more capable of carrying a pressure wave than slower-moving molecules. As a consequence, heat makes sound travel faster as well.



3. What is resonance? Grab a piece of PVC, a container of water and a tuning fork. Recreate the setup shown below:



When the tuning fork is struck and held near the open end of the tube, it produces a series of compressions and expansions (rarefactions) in the air inside the tube. These compressions and expansions create sound waves that travel down the tube and reflect off the surface of the water. If the frequency of the tuning fork matches the natural frequency of the tube (also known as the resonant frequency), the sound waves produced by the tuning fork will be in phase with the standing waves in the tube. This will cause the compressions and expansions to reinforce each other, resulting in a louder sound at the open end of the tube. Since they are in phase, all of their energy will add so that the amplitude is now equal to the sum of the amplitudes of both waves. This is called constructive interference.

By sliding the pipe up and down in the cylinder, you can change the effective length of the tube, which will change its resonant frequency. When you find a position where the sound is louder, it means that the frequency of the tuning fork is close to the resonant frequency of the tube at that length. By repeating the procedure with tuning forks of different frequencies, you can determine the resonant frequencies of the tube at different lengths. This can help you understand the relationship between the length of the tube and the frequencies at which it resonates.

Why do some people associate resonance with the "seashell effect?" Resonant sounds are created from ambient noise in the surrounding environment by the processes of reverberation and (acoustic) amplification within the cavity of the shell. The ocean-like quality of seashell resonance is due in part to the similarity between airflow and ocean movement sounds. The association of seashells with the ocean likely plays a further role.

Vocabulary Terms:

- **Amplitude:** the maximum extent of a vibration or oscillation, measured from the position of equilibrium.
- **Antinode:** the position of maximum displacement in a standing wave system.
- **Crest:** the point on a wave with the greatest positive value or upward displacement in a cycle.
- **Displacement:** A change in the position of an object
- **Frequency:** The number of waves that pass a given point in one second, unit is called Hertz (Hz=1/s)
- **Medium:** A substance that enables energy transfer from one location to another, especially through waves.
- **Node:** A node is a point along a standing wave where the wave has minimum amplitude
- **Resonance:** occurs at the frequency known as the resonance frequency. At this specific frequency, the energy in the system grows and can reach its breaking point.
- **Sine Wave:** a curve representing periodic oscillations of constant amplitude as given by a sine function.
- **Speed of Sound:** The speed of sound is the distance traveled per unit of time by a sound wave as it propagates through an elastic medium.
- **Trough:** The lowest point on a wave.
- **Velocity:** The speed and direction of a given object.
- **Vibration:** an oscillation of the parts of a fluid or an elastic solid whose equilibrium has been disturbed, or of an electromagnetic wave.
- **Wavelength:** one cycle of traveling wave (equal positive and negative displacement), can easily be measured from crest to crest, trough to trough, or every other point crossing the equilibrium position.

STEM Related Careers:

- Acoustic Technician
- Sonar Technician
- Naval Sonar Engineer
- Underwater Warfare Specialist
- Oceanographer

Notes

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The Seaworthy STEM™ in a Box curricula was developed through collaborative efforts of a team of individuals at the Naval Surface Warfare Center Carderock Division and Albert Einstein Distinguished Educator Fellows via an inter-agency agreement with the U.S. Department of Energy for the Albert Einstein Distinguished Educator Fellowship (AEF) Program. We are grateful to the following Content Specialists who contributed their knowledge and expertise by researching and writing on selected topics: Suzanne Otto, Stephanie Klixbull, Thomas Jenkins and Melissa Thompson. We'd also like to acknowledge the contributions of AEF participant Ms. Deborah Reynolds, the inaugural AEF Educator at Carderock that helped inspire the design of Seaworthy STEM™ in a Box content. Special thanks to Albert Einstein Fellow Melissa Thompson, for the creation of a collaborative high school engineering curriculum and supplemental additions to the early grade bands; career portfolios, workforce trading cards, and in-house short story publications. Gratitude to Carderock Outreach Specialist Ashlee Floyd, STEM Program Manager, Charlotte George, and Media Specialist Kristin Behrle for the creation and support of this naval endeavor that showcases the diversity of NAVSEA Sites.

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