Building Sustainable Ships

Companion Lesson to X-STEM All Access Episode "Sustainable Ships"

Grade Band: Middle School - High School	**Topic**: Engineering, Physics, Sustainability

Brief Lesson Description: Students design and test a ship structure that must be both strong and low-carbon, learning how forces, materials, and shape affect energy use and greenhouse gas emissions.

Performance Expectation(s):

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.

HS-ESS3-4 Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

MS-ETS1-2 Evaluate competing design solutions using a systemic process to determine how well they meet the criteria and constraints of the problem.

MS-ESS3-3 Apply scientific principles to design a method for monitoring and minimizing human impact on the environment.

Specific Learning Outcomes:

Students will be able to:

-explain and model how compression, tension, and bending forces act on a ship's structure when it moves through waves, using diagrams and test data from their beam experiments.

-design, build, and test a ship structure that maximizes load capacity while staying within material and carbon constraints, using data to improve their design.

-evaluate how ship mass, shape, and material choices affect fuel use and greenhouse gas emissions, and justify at least one design change that reduces environmental impact.

Narrative / Background Information

Modern shipbuilding isn't just about making something that floats—it's about building ships that can handle huge forces while using as little energy and material as possible. As ships move through waves, their hulls bend and twist, with the top being squeezed and the bottom being pulled apart. In the past, when engineers didn't fully understand these forces, real ships failed—some World War II cargo ships even cracked in half. Today, engineers use smart shapes, ribs, and internal frames to spread those forces out, which is why modern ships are so much stronger without being heavier. That's the same idea students see when their folded paper beams hold more weight than flat ones.

At the same time, shipping has a big impact on the climate because moving heavy ships through water takes a lot of fuel. The heavier and less efficient a ship is, the more pollution it creates. That's why ship designers now focus on making ships that are strong but light and shaped to move easily through water. In this lesson, students are dealing with the same trade-offs real engineers face—how to make something that's safe, affordable, and better for the planet. It helps them see that good engineering isn't just about building things, but about building things in a smarter, more responsible way.

Science & Engineering Practices:	**Disciplinary Core Ideas:**	**Crosscutting Concepts:**
Constructing Explanations and Designing Solutions Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-2, HS-ESS3-4) Apply scientific principles to design an object, tool, process or system. (MS-ESS3-3) **Engage in Argument from Evidence** Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MS-ETS1-2)	**ETS1.B: Developing Possible Solutions** When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics and to consider social, cultural, and environmental impacts. (HS-ESS3-4) There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2) **ETS1.C: Optimizing the Design Solution** Criteria may need to be broken down into simpler ones that can be approached systemically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)	**Cause and Effect** Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation. (MS-ESS3-3) **Stability and Change** Feedback (negative or positive) can stabilize or destabilize a system. (HS-ESS3-4) —-- ***Connections to Engineering, Technology and Applications of Science*** **Influence of Science, Engineering, and Technology on Society and the Natural World.** Engineers continuously modify these

	ESS3.C: Human Impacts on Earth Systems Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. (HS-ESS3-3) Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things. (MS-ESS3-3) Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise. (MS-ESS3-3)	technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HS-ESS3-3) The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time. (MS-ESS3-3)

Possible Preconceptions/Misconceptions:

1. Misconception: Heavier ships are always stronger and safer.
Why this is wrong: Strength depends more on shape and how material is arranged than on how much material there is.

2. Misconception: If a ship floats, its structure doesn't really matter.
Why this is wrong: Waves constantly bend and twist ships, and weak structures can crack even if the ship stays afloat.

3. Misconception: Green ships only need cleaner fuel, not better design.
Why this is wrong: Poorly designed, heavy ships use more energy and create more emissions no matter what fuel they burn.

4. Misconception: Engineering is just building something once and being done.
Why this is wrong: Real engineers test, analyze, and redesign because improvement comes from learning what didn't work.

LESSON PLAN – 5-E Model

ENGAGE: Opening Activity – Access Prior Learning / Stimulate Interest / Generate Questions:

You will start the lesson with students observing slide 2 of the slide deck showing Amazon packages, a container ship, and an infographic about CO_2. Students should share their initial ideas around what they notice and wonder about these images. (Expected answers include we live in a culture that ships most everything, container ships bring goods from around the world, and the cost of these deliveries is higher CO_2 resulting in environmental impacts).

Explain that modern shipbuilders must consider this when they are designing ships. Show the X-STEM All Access episode "Sustainable Ships" featuring Isabella Jimenez-Melendrez. Have students discuss what stood out to them from the video. Then discuss the question ***"Why does moving stuff across oceans take so much energy?"***

EXPLORE: Lesson Description – Materials Needed / Probing or Clarifying Questions:

Explain to students that they will be exploring the answer to these questions through an exploration of structural engineering. Next, have students observe slide 3 of the slide deck showing a beam that is folded versus a flat beam. Ask them ***""Why does the folded one hold more without weighing more?"***

Students will work in pairs or small groups to compare three different beam structures. Prior to the exploration, each group will need 3 pieces of copy paper, weights and a scale/balance. For weights, you can use what is locally available including pennies, washers, or weight sets. For many students it is helpful to keep the slide up as a visual of how to set up the activity. Provide each student with a Sustainable Ships Exploration Handout. As students work through the challenge, circulate between groups reminding them that they are NOT adding tape and/or glue.

After data collection, discuss their findings/answers to the *Think Like an Engineer* questions from the hand out.

1. Which beam was the most efficient? Why?

2. Why does a stronger beam mean lower fuel use for ships?

Extend the discussion to the idea of forces by asking students to identify/describe what forces they think are at play.

EXPLAIN:
Introduce students to the Explain text using slide 4 of the slide deck. Have students work independently, complete reading the Building Sustainable Ships Text and answering the ***"Stop and Think"*** questions.

As a class, discuss the information. Key topics for the class include:
-Compression & tension
-Bending & flexing
-Weight → drag → fuel → CO_2.

Summarize the key idea: **The most climate-friendly ship is the strongest ship for the least material.**

ELABORATE: Applications and Extensions:
Introduce students to the "Next-Gen Shipyard: The Low Carbon Ship Challenge" using slide 5 of the slide deck. Students are tasked with creating a low-carbon ship design that carries the most weight with the least carbon output.

Students can complete the design challenge individually or in groups of 2-4 students. Each group should complete the design challenge as guided by the handout.

You will need to provide a variety of materials that are easily sourced including straws (bamboo if you want to be sustainable), tape, cardboard, and popsicle sticks. It is also useful to provide scissors, box cutters, rulers, pencils, and markers to help with the construction process.

EVALUATE:

Formative Monitoring (Questioning / Discussion):
Discussion questions throughout the lesson are found in bold italics that can be used as formative assessment. Additionally, teachers can use student responses on the exploration handout and the Building Sustainable Ships Text.

Summative Assessment (Quiz / Project / Report):
A rubric is provided on the handout for students to be assessed on their reflection and data analysis of the design challenge. Additionally, students may present their findings to the class for a final assessment.

Elaborate Further / Reflect: Enrichment:
Students may extend their thinking through one of the following activities:

1. Students take their tested ship design and must **redesign one feature** to reduce greenhouse gas impact *without losing strength*.
2. Students can use photographs of failed beams to do a **failure analysis** and answer questions such as "Where did it fail?", "Was it tension, compression, or shear?", and/or "What design change would prevent it?".
3. Students can watch the video "Tour of a Container Ship" and then suggest possible ways to **redesign features** to reduce carbon emissions.

CAREER CONNECTIONS

There is a wide variety of careers students can pursue in the Transportation Building Industry. From designing ships for the Navy to working on research vessels, students can find a variety of careers to pursue. The following activity will provide students an opportunity to learn about these careers.

Go to https://usasciencefestival.org/resources/ to access the Student Career Resources.

Select the "Land, Air, & Sea Vehicles" category.

Have students browse the careers within your chosen cluster. Select one career that they would like to learn more about. They should then gather the following information using the student graphic organizer or in a class notebook:

- Job description and typical responsibilities
- Education and training required
- Skills and qualities needed

- Average salary
- Work environment and schedule
- Professional Organizations, Educational Programs, and Internship & ApprenticeOpportunities

Choose a Choice Board Activity and use the information gathered to complete the chosen activity.

Resume for the Future Create a resume as if you are applying for a job in your chosen career 10 years from now. Include education, experience, and skills.	**Work Environment Design** Draw or digitally create an image of the typical work environment for this career. Annotate it with labels explaining the features.	**Career Advertisement** Create a commercial (video or audio) to promote your chosen career to others. Highlight its benefits and opportunities

Provide students an opportunity to share their findings with peers or with you.

FUTURE-READINESS TOOLKIT

Competency Addressed: Communication

The goal of this activity is for students to explain how communication and shared strengths help teams succeed—just like strong structures in ship design. *This activity is best used between the Explain and Elaborate portions of the lesson.*

1. Show a quick diagram or photo of a ship hull with internal ribs. Ask students, ***"What would happen if all the strength were in just one part of the ship?"*** Expected answers include cracking, twisting, failure, etc.

2. Pivot and ask students, ***"What happens if only one person in a group does all the thinking or talking?"*** Expected answers include resentment, missed ideas, conflict, poor designs, etc.

3. Provide students time to answer the question **"How does communication in a team relate to the strength of a ship?"** After students discuss, post **Strong ships and strong teams distribute load.** Ask students what they think this means.

4. Provide each student with a copy of the "Team Communication Check-In". Explain that students will complete this individually and then discuss it as a team. As students work on it individually, teachers should circulate and provide prompting for students who rush or struggle.

5. Have teams discuss their own check-ins together. Ask them to choose their favorite reflection sentence and share as a class. These can be recorded on anchor charts for students to refer to throughout the rest of the school year.

Materials Required for This Lesson/Activity	
Quantity	**Description**
Class Set of each of the following	Popsicle sticks, straws, tape, and cardboard (~12"x12")
	Rulers
	Scissors
	Box Cutters
	Pencils
	Markers

Lesson Created by Jess Noffsinger
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