Finite Element Analysis Lesson Plan

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RET Rationale and Goals

a) These lessons were created to introduce students to computational models using finite element analysis. Due to the advanced nature of the topic, this series of lessons begins with real-world basics to ground the students' learning in prior knowledge. The later lessons include more abstract concepts such as stress, tension, and ultimately finite element analysis. By completing this unit, it is hoped that the students gain technical knowledge currently used in biomechanics and engineering.

b) Each lesson uses scaffolds to help diverse learners including appropriate visuals, sentence stems, vocabulary cards, graphic organizers, and whole class modeling. Every lesson has a language or sensory activity to promote language acquisition in reading or writing and to encourage participation and pro-social behavior. These lessons include a balance of science, technology, and language arts concepts to help students become well-rounded learners and communicators of science.

Lesson 1: Three Little Pigs	**Time:** 50 minutes
Grade Level: 11th	**Subject:** Physics
CCSS Standards: RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.	**WIDA Standard:** 1. Name properties of materials (Speaking ELP 1) 2. Compare properties verbally (Speaking ELP 4) 3. Integrate diagrams to describe objects (Writing ELP 4)
Content Objective: HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.	**Language Objectives:** Students will compare and describe properties of materials using vocabulary words

Introduction

Students watch a video where a watermelon is covered with an "indestructable" polymer and survives a drop from a large tower. https://thewonderofscience.com/phenomenon/2018/7/9/indestructible-coating-polyurea

Probing questions: What does the materials look like at a molecular level and how does this help?	**Possible answers:** The molecular structure is jumbled fibers that can stretch to avoid breaking.
What would you use an indestructible coating for?	Maybe.. a phone case?
Why was the coating able to save the watermelon?	The coating stretched and caused the watermelon to bounce.

Guided Practice

1. Students will analyze up-close pictures of materials and guess what they are made of.
   a. *EL modification: Students will be given a word bank of possible answers*
   b. Vocabulary: Cotton, glass, metal, foam, styrofoam, cardboard, wood, plastic, brick
2. The students will put the pictures into groups to describe their properties.
   a. *EL modification: Students will be given real examples of each material and definitions.*
   b. Vocabulary: Hard, soft, toughness, elastic, rigid, elasticity, ductile, brittle
3. The class will choral read The Three Little Pigs. Students are given 1 line in the story.
   a. *EL modification: EL students are given shorter passages or a translation. A peer can help sound out the sentence before reading out loud.*
   b. https://lionwoodinfant.co.uk/wp-content/uploads/2021/01/Yr1-The-Three-LIttle-Pigs-Story-PowerPoint.pdf

4. Students will discuss the events in the story in think-pair-share format.
   a. *EL modification: Questions are shown on the board in English and Spanish.*

Question: What is the theme of the story? Why would you want your house to be strong?	**Possible answers**: The strongest house will keep out the wolf. Security, weather, lasts longer
What do you know about straw, wood and brick?	Wood and brick are hard. Straw is soft and light
Why did the pigs choose straw and wood? Why didn't they use brick?	They were inexpensive/easy to make and take less time

Independent Practice

1. Students will explain the materials used by the Three Little Pigs using the vocabulary words.
   a. *EL modification: Students can use vocabulary and sentence stems.*
      Example: The first pig used ______, which is a _______ material.

Assessment

1. Students will be asked to evaluate a list of materials on their ability to protect an object. Students will be assessed on their ability to describe the properties of materials using the vocabulary terms

Materials	**Description**	**Would this make a good phone case?**
1. Foam 2. Plastic 3. Metal 4. Rubber 5. Glass 6. Wood	1. Hard, brittle, rigid	1. No, it would break apart

Extension

1. Students will be asked to draw what they think plastic molecules (polymers) look like. The different type of plastics and the scale of microplastics are also discussed.

Lesson 2: Broken Phone Lab	**Time:** Two 50 minutes class periods
Grade Level: 11th	**Subject:** Physics
CCSS Standards: WHST.11-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.	**WIDA Standard:** 1. Name properties of materials (Speaking ELP 1) 2. Compare properties verbally (Speaking ELP 4) 3. Integrate diagrams to describe objects (Writing ELP 4)
Content Objective: HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.	**Language Objectives:** Students will design an experiment using given materials and present their design.

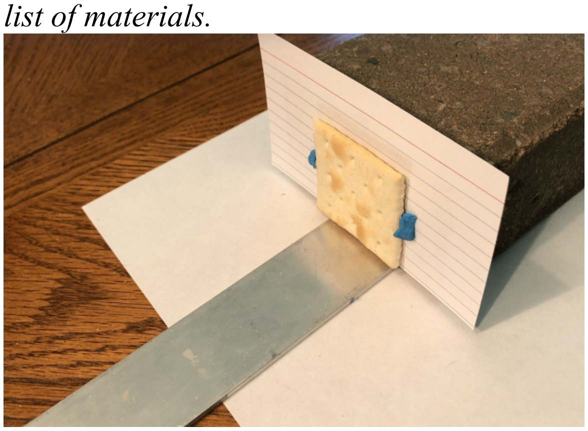
Introduction

1. The teacher asks if the students have seen a phone screen break. Students will describe their experience in their notebook.
    a. *EL Modifications: Sentence stem provided and students will think-pair-share ideas*

Guided Practice

1. The students will begin writing notes about peak force (maximum stress for a material).
    a. *EL Modifications: Notes provided with blanks*
2. The students are given video examples of real equipment used to measure peak force.
3. The teacher asks the students to brainstorm things that could decrease the peak force
    a. Possible answers: padding, cushioning, elastic material

Independent Practice

1. The students will design an experiment to answer the question: How can we measure the force that will break a cracker? Students must list the materials, procedure, and a diagram.
    a. *EL Modifications: Students are provided with a graphic organizer, sentence stems, and a list of materials.*
    b. 
    c. Materials: Crackers, set of weights, ramp, cart, plastic bag, ruler

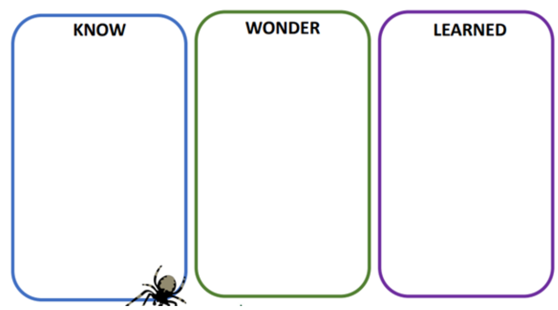
Assessment 1. The students will share their designs with the class on poster paper as a presentation to explain why their experiment design would work.   a. *EL Modifications: Students will be given sentence stems to describe components and the practical qualities of a system.*

Extension
1. Students read short articles about the ball-burst and tensile testing machine.
    a. Ball burst machine: https://www.instron.com/wp-content/uploads/2024/07/ball-burst-test-in-accordance-with-astm-d-6797.pdf
2. Students can perform a virtual experiment using a tensile test machine
    a. https://impvis.co.uk/launch/virtual-materials-lab-tensile-test/tensile.html

Lesson 3: Spider "Web"quest	**Time:** Two 50 minutes class periods
Grade Level: 11th	**Subject:** Physics
CCSS Standards: RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.	**WIDA Standard:** 1. Summarizing content-related material (Writing ELP 3) 2. Identifying detailed descriptions, procedures, and information in paragraphs (Reading ELP 3) 3. Labeling charts, graphs, timelines, or cycles to describe phenomena (Writing ELP 1)
Content Objective: HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.	**Language Objectives:** Students will use technology to research questions and synthesize information into a graphic organizer.

Introduction

Students will begin by writing what they "know" and "wonder" about spider webs in a KWL chart in their notebook. Students will watch a video on the strength of spider silk. Why Spider Silk is Stronger Than Steel (Start time: 4m20s End time: 9m33s)



Guided Practice

1. Students will write what they learned about spider webs in the KWL chart. The class will share ideas and write new ideas.
    a. *EL modification: Students can get ideas from their peers before sharing.*

Probing questions: What do you think is stronger: steel or spider silk?	**Possible answers**: Students take either side.
What does "strength" mean?	Toughness, ability to compress, etc
What can a stress vs strain graph tell us? What does it not tell us?	Maximum strength, toughness, point of fracture. It does not show how much material or the temperature.

Independent Practice

1. Students will begin working on a "web" quest. Every question requires a written answer and illustration.
    a. *EL modification: Students can work in groups where they share the web quest tasks. EL students can be given specific tasks in the group such as recording information or drawing. Students will be given a graphic organizer to write information. Printed versions of the websites and translations will also be available.*

1) Students define stress, strain, and Young's Modulus
    a) https://www.fidelisfea.com/post/stress-and-strain-what-are-they-and-what-is-their-relationship
    b) http://hyperphysics.phy-astr.gsu.edu/hbase/permot3.html
2) Students compare the tensile strength of 7 different materials.
    a) http://hyperphysics.phy-astr.gsu.edu/hbase/permot3.html
3) Students will describe the properties and applications of spider silk
    a) https://www.highdown.reading.sch.uk/attachments/download.asp?file=493&type=pdf
4) Students illustrate the molecular composition of spider silk.
    a) https://ednieuw.home.xs4all.nl/Spiders/InfoNed/webthread.html
    b) https://www.chm.bris.ac.uk/motm/spider/page3.htm
5) Students research the factors affecting tensile strength
    a) https://www.xometry.com/resources/3d-printing/tensile-strength/
6) Students research the strength of a web using computer models
    a) https://a5833959.medium.com/ansys-structural-optimization-spider-web-f8504886b5fe
    b) https://www.researchgate.net/figure/Mechanical-properties-of-the-silks-of-Darwins-bark-spider-in-comparison-to-the_fig2_260342083
    c) https://www.researchgate.net/figure/a-Calculation-model-for-an-orb-web-subjected-to-the-normal-impact-of-a-prey-and-b_fig2_327427599

Assessment

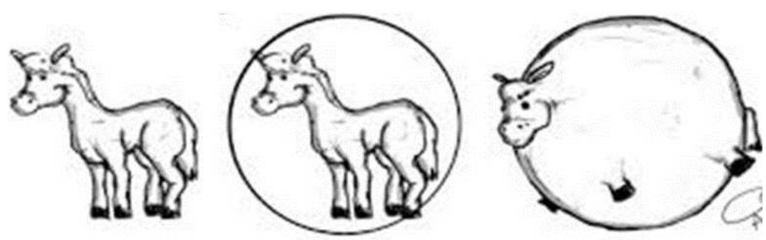
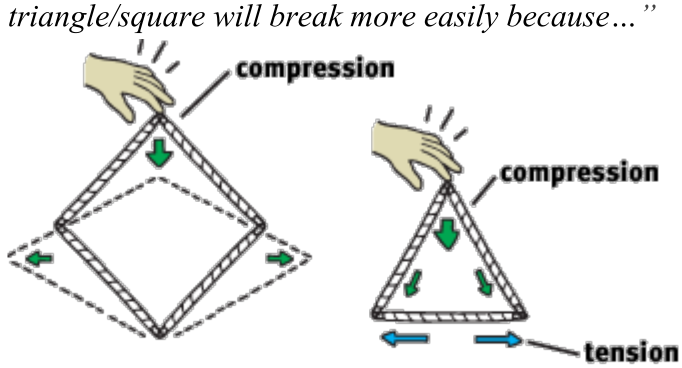
1. Students will use the information they found to create a poster presentation. Student groups will have different topics to consider. Every poster is required to have an explanation and a graphic.
    a. *EL modification: EL students are grouped with peers and given tasks such as comparing instead of explaining. Students have the option to create a poster using technology.*

Topic 1: Explain all the parts of the stress-strain graph for spider silk
Topic 2: Explain how the molecular structure of spider silk makes it strong
Topic 3: Describe applications of spider silk and discuss any limitations
Topic 4: Compare the tensile strength of spider silk with other materials
Topic 5: Describe the strength of a spiderweb using finite element analysis

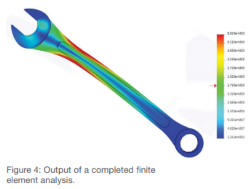
Extension
The difference between amorphous and crystalline lattice structures can be added to the webquest.

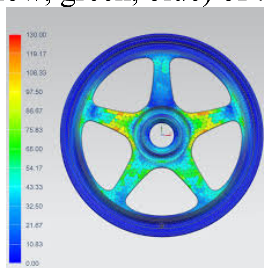
Lesson 4: Finite Element Analysis	**Time:** 50 minutes
Grade Level: 11th	**Subject:** Physics
CCSS Standards: RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.	**WIDA Standard:** 1. Students will identify causes for phenomena in short oral presentations (Speaking ELP 3) 2. Students will suggest creative ways to resolve communication issues (Speaking ELP 3)
Content Objective: HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.	**Language Objectives:** Students will draw pictures using verbal descriptions and make inferences about materials using evidence.

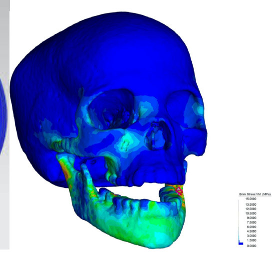
Introduction

1. Students will be given a yes or no statement to analyze: “A horse can be regarded as a perfect sphere.” Students should come to the conclusion that a horse is more complex and is a combination of shapes and “nodes.”
    a. 
2. Students are given magnetic building sticks. Students create a square and a triangle. Students are asked what happens if a force is exerted on a corner and shape would break more easily.
    a. *EL Modifications: Students are given sentence starters: “The shape will..” “The triangle/square will break more easily because…”*
    b. 

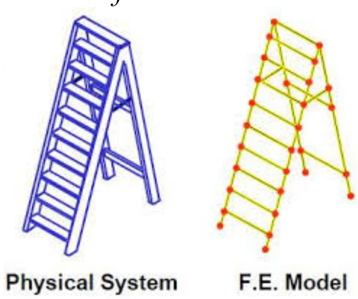
Guided Practice

1. The students will be given the task of drawing a "secret picture." This is a picture of an everyday object that one student will draw based on the explanation of their group members. The drawing includes a color map (red, yellow, green, blue) of the stress an object receives when in use.
    a. 

    
2. After student groups have drawn the model, the class will share results and discuss why certain areas were different colors (Ex: this part is thinner, this part is fragile, this part gets more force when you hold it). Students will come up with reasoning as a group.
    a. *EL modifications: The describing student will be given vocabulary such as the names of colors and the name of the object. Students work as groups to explain the colors.*

Independent Practice

1. Students will get their own picture of an object to add nodes and a color map for stress. The student also describes why they colored certain parts of the system red or blue.
    a. *EL Modifications: Students can use the explanations from the group activity as an example.*
    b. 

Assessment

1. The students will be given the correct color map corresponding to their object. The student will compare their stress map to the real example, stating what parts they may have colored differently.
    a. *EL Modifications: Students will be given a Venn diagram to organize their findings.*

Extension

Students can research their own objects to create stress maps.

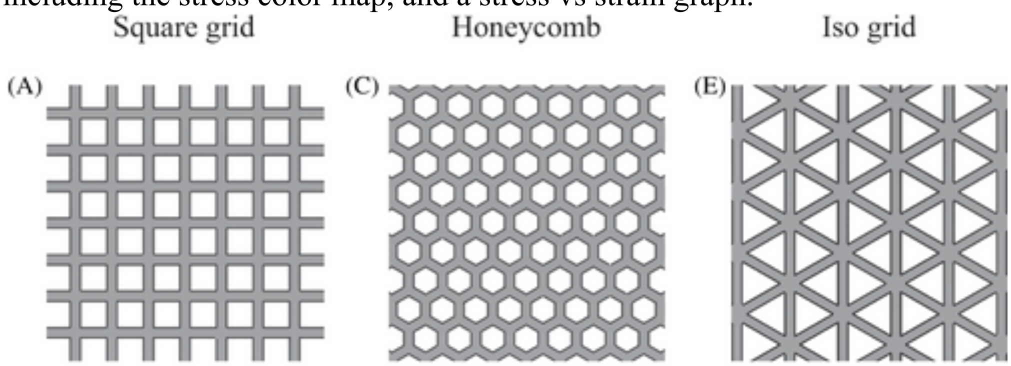
Lesson 5: Lattice Structures	**Time:** 2 50 minute class periods
Grade Level: 11th	**Subject:** Physics
CCSS Standards: WHST.11-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.	**WIDA Standard:** 1. Summarizing information with diagrams, models, flow charts, or illustrations (Reading ELP 3) 2. Including images, diagrams, and charts to add details to the topic (Writing ELP 1) 3. Choosing words and phrases to provide precise details, descriptions, comparisons, and ordered procedures (Writing ELP 3)
Content Objective: HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.	**Language Objectives:** Students will write and follow an experimental procedure and communicate data and results.

Introduction

1. Students will watch a video on phone case manufacturing. Students are asked to explain the steps they saw in the video, including cutting, molding, and pressing. Mobile Phone Case Manufacturing Process
2. Students will be asked to create a phone case. The following robing questions will be asked to help them brainstorm.

Probing questions:	**Possible answers:**
What properties are needed in a useful phone case (the criteria)?	Does not shatter or break, absorbs energy, can be elastic or bounce when dropped
What would be the constraints (what is out of our control when we make a phone case)?	The size, cost of material, labor, etc
What kind of material would be the best? What are cases usually made of?	Elastic like rubber, easy to make like plastic
How can stress and strain help us create a model for a phone case?	Stress and strain can give us information on where the material is weak.

Guided Practice

1. Students will watch four examples of compressed materials using finite element analysis.
    a. Finite Element analysis of a Lattice Structure using opensource tools (3d example)
    b. How to model lattice structures with periodic boundary conditions. (iso grid)
    c. How to model hexagonal lattices with periodic boundary conditions (honeycomb)
2. Students will be asked to create a phone case using one of the lattice patterns. The students are given examples of each lattice (square, honeycomb, and iso grid), the finite element analysis results including the stress color map, and a stress vs strain graph.
    a. 

    Adapted from https://onlinelibrary.wiley.com/doi/full/10.1002/eng2.12701
3. Student teams will be assigned a lattice shape. The pattern is printed on white paper and placed inside a plastic sandwich bag. Students are asked to trace the pattern on top of the sandwich bag using hot glue to create a glue lattice.
    a. 
4. As one student is gluing, another student begins labeling the stress strain graph for their lattice.
    a. *EL modification: An example stress-strain graph with labels is used for comparison*
    b. Labels: Yield strength, Young's modulus (initial slope), point(s) of fracture

Independent Practice

1. When the glue dries (about 5 mins), the students can begin performing an experiment to determine the peak force before breaking a cracker. A cracker is placed inside the sandwich bag and the students repeat the steps from Lesson 2- Broken Phone Lab.
2. The students should record what weight breaks the cracker inside the glue lattice bag (using a new cracker for every trial) and illustrate the shape of the cracker when it is ruptured.

Assessment

1. Students will present their results to the class using a poster presentation. Poster must follow scientific method. Students can use their procedure from lesson 2.

a. *EL Modification: Students are given an example of the scientific method.* b. Vocabulary: Question, hypothesis, materials, procedure, results, data, conclusion
Extension Alternative experiment: Students add weight onto the lattice to find the peak strength of the glue mold.

NAME

SPIDER WEBQUEST

Go to: https://www.fidelisfea.com/post/stress-and-strain-what-are-they-and-what-is-their-relationship

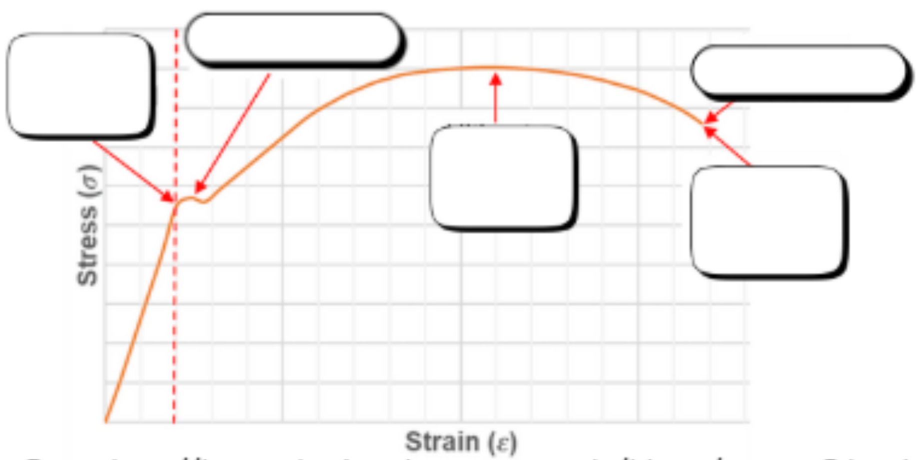
1. Fill in the blanks of the definitions.

Stress: The amount of _________ or ________ applied over the area.

Strain: Measures the ____________ of an object

Young's Modulus: A way to quantify the __________ of various materials

2. Label all parts of the stress-strain graph

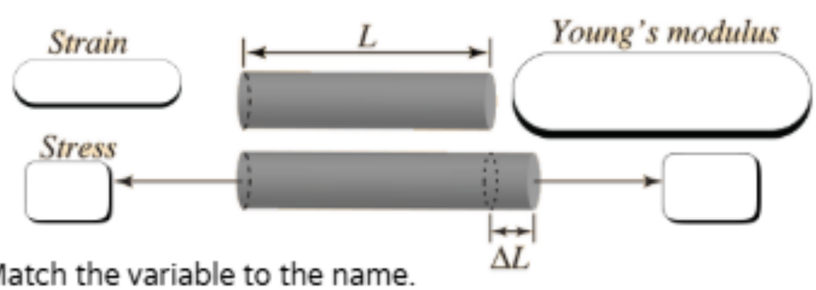


Word Bank

- Elongation at break
- Fracture point
- Proportional limit
- Yield point
- Ultimate tensile strength

Go to: http://hyperphysics.phy-astr.gsu.edu/hbase/permot3.html

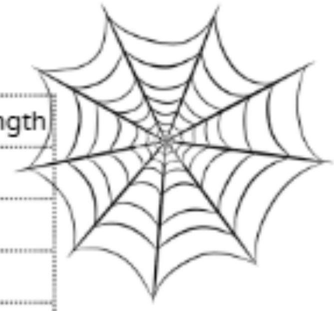
3. Finish the diagram.



4. Match the variable to the name.

F	Length
L	Change in length
A	Force
ΔL	Area
E	Young's Modulus

5. Compare the elastic properties of different materials.



Material	Density	Young's Modulus	Ultimate Strength	Yield Strength
Steel				
Aluminum				
Glass				
Concrete				
Wood				
Bone				
Polystyrene				

a. What is the most dense material on the list? ____________________

b. What is the least dense material on the list? ____________________

c. What is the most stiff material on the list? ___________________

d. What is the least stiff material on the list? ___________________

e. What is the strongest material on the list? ____________________

f. What is the weakest material on the list? _____________________

g. What is the common word for polystyrene? ____________________

h. What is the difference between ultimate strength and yield strength (yield point)?

The ultimate strength is ____

but yield strength is the point where ____

The _______________ *strength comes before the* ________________ *strength on a stress-strain curve.*

Go to https://www.highdown.reading.sch.uk/attachments/download.asp?file=493&type=pdf

6. Write down what you learn about the properties of spider silk.

Strength: A dragline silk's tensile strength is comparable to that of high grade alloy _____.

Density: Silks are about a _____ of the density of steel.

Extensibility: Silks are also extremely _______, with some able to stretch up to ____ times.