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Unit Title: Finite Element Analysis (FEA)

Stage 1 – Desired Results

Transfer Skills

Technical and Analytical Skills

1. Numerical Methods Understanding

- Application of discretization, interpolation, and numerical integration techniques.

2. Problem Solving and Modelling

- Ability to model complex physical systems mathematically and interpret simulation results.

3. Software Proficiency

- Experience with industry-standard FEA software.

4. Data Interpretation and Visualization

- Skills in analyzing and visualizing stress, strain, deformation, and other outputs.

5. Validation and Verification

- Understanding of how to validate models and check results against analytical or experimental data.

Cognitive and Critical Thinking Skills

1. Critical Thinking

- Evaluating assumptions and simplifications in models.

2. Logical Reasoning

- Breaking down complex problems into solvable finite elements.

3. Attention to Detail

- Recognizing and correcting errors in mesh design, boundary conditions, and solver settings.

Engineering and Design Skills

1. Structural and Mechanical Insight

- Understanding how components behave under various loading conditions.

2. Design Optimization

- Using FEA to improve product performance and safety through iterative design.

3. Multidisciplinary Integration

- Applying FEA in combination with physical and structural analysis.

Professional and Interpersonal Skills

1. Project Management

- Managing time, scope, and deliverables within simulation-based projects.

2. Communication

- Clearly documenting and presenting complex findings to both technical and non-technical audiences.

3. Team Collaboration

- Working within teams to share models, run simulations, and interpret collective results.

Transferable Thinking Skills

1. Abstraction and Generalization

- Applying FEA thinking (discretization, boundary conditions, etc.) to other complex systems.

2. Computational Thinking

- Developing an algorithmic approach to problem-solving using simulation workflows.

3. Adaptability

- Ability to apply FEA principles in various domains (e.g., biomechanics, civil structures, automotive, aerospace).

These skills not only support careers in engineering but also in data science, computational physics, applied mathematics, and systems design.

Established Goals

Students who demonstrate understanding can:

HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking

Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems.

Disciplinary Core Ideas

ETS1.B: Developing Possible Solutions

- Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.

Crosscutting Concepts

Systems and System Models

- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.

Connections to HS-ETS1.B: Developing Possible Solutions Problems include:

Earth and Space Science: HS-ESS3-2, HS-ESS3-4 **Life Science:** HS-LS2-7, HS-LS4-6

Articulation of DCIs across grade-levels:

MS.ETS1.A ; MS.ETS1.B ; MS.ETS1.C

Common Core State Standards Connections:

Mathematics -

MP.2 Reason abstractly and quantitatively. (HS-ETS1-4)

MP.4 Model with mathematics. (HS-ETS1-4)

Students who demonstrate understanding can:

HS-PS2-6. **Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*** [Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Obtaining, Evaluating, and Communicating Information Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs. Communicate scientific and technical information (e.g. about the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).	PS2.B: Types of Interactions Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.	Structure and Function Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.
Connections to other DCIs in this grade-level: N/A		
Articulation of DCIs across grade-bands:		
MS.PS1.A ; MS.PS2.B		
Common Core State Standards Connections:		
ELA/Literacy –		
RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS2-6)		
WHST.11-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-PS2-6)		
Mathematics –		
HSN.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS2-6)		
HSN.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. (HS-PS2-6)		
HSN.Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS2-6)		

Meaning - Understandings

Students will ...

- Understand that FEA is a numerical method for solving complex engineering problems involving structures, heat transfer, fluid flow, etc.
- Recognize that FEA works by breaking a complex domain into smaller, manageable pieces (finite elements).
- Understand the role of nodes (points) and elements (the regions connecting nodes) in creating the mesh.
- Identify the types of physical problems solved by FEA, including structural (stress/strain), thermal, and fluid dynamic problems governed by differential equations.
- Understand how boundary and loading conditions affect the accuracy and validity of an FEA model.
- Appreciate the importance of mesh size, refinement, and element quality on solution accuracy and convergence.
- Understand how material models (e.g., linear, nonlinear, isotropic, anisotropic) are incorporated into FEA simulations.
- Be able to interpret results such as displacement, stress, strain, or temperature distributions.
- Understand the importance of verifying the model setup and validating results against analytical or experimental data.

Meaning - Essential Questions
<i>Students will keep considering</i> ○ How can complex physical systems be broken down into simpler parts to understand and solve them more effectively? ○ What mathematical and physical principles govern the behavior of structures, materials, or systems under various conditions? ○ When is it appropriate to rely on numerical models like FEA, and what are the limitations of these models? ○ How can we verify and validate the outcomes of a simulation to ensure they reflect real-world behavior? ○ What trade-offs exist between model simplicity, computational cost, and solution accuracy in engineering analysis? ○ How can simulation tools like FEA support better design, innovation, and safety in engineering applications?
Acquisition – Knowledge
<i>Students will know</i> ○ Finite Element Analysis is a numerical method used to approximate solutions to complex engineering and physical problems. ○ Physical domains can be discretized into finite elements and nodes to make mathematical modeling manageable. ○ The basic steps of the FEA process: pre-processing (model setup), solving (computation), and post-processing (results interpretation). ○ The importance of verifying the model setup and validating simulation results against theoretical or experimental data. ○ FEA results are approximations and must be critically evaluated for assumptions, limitations, and potential sources of error. ○ FEA tools support engineering design, analysis, and decision-making across a range of industries.
Acquisition - Skills

Students will be skilled at...

- Identifying potential modeling errors or unrealistic assumptions in a finite element model.
- Validating simulation results by comparing them with theoretical predictions or experimental data.
- Communicating findings clearly through technical reports, including visualizations and justifications of model choices.
- Applying critical thinking to evaluate the limitations and reliability of numerical simulations in engineering design and analysis.

Stage 2- Evidence

Evaluative Criteria

- [Pre-Lesson Google Form](#)
- [Post-Lesson Google Form](#)

Performance Tasks

- Hands-on worksheets
- Group problem-solving tasks
- Class discussions and reflections
- Rubric-based feedback on model quality and communication

Other Evidence

Students will receive daily formative assessments that are designed to measure the daily objective and provide feedback to the students with respect to their progress. These daily objectives are directly related to and guided by the learning objectives for the unit. Interventions and Accelerations will serve as practice work and will be self-graded by the students (using a rubric) to provide another form of feedback.

Stage 3- Learning Plan

Work in Progress

Day 1: Introduction to Finite Element Analysis

Objective:

Students will understand the fundamental concepts of finite element analysis and its application in solving engineering problems.

Activities:

- Pre-Lesson Google Form
- [Lecture/Presentation](#):
 - What is FEA?
 - Historical context and real-world applications (bridges, aerospace, biomedical, etc.)
 - Concepts of discretization, elements, nodes, boundary conditions, and meshing.
- Demonstration: Visual simulation of a basic FEA model (e.g., simple beam under load).
- Discussion: Benefits and limitations of FEA.
- Quick reflection: Students write a short paragraph summarizing what FEA is and one real-world application.

Day 2: Building Physical Models – Bridge Sections with Varying Fiber Orientations

Objective:

Students will model bridge sections with different fiber orientations to understand how material structure influences mechanical behavior.

Activities:

- Hands-on activity:
 - Students construct physical models of bridge sections
 - Three groups: (1) Regular fiber orientation, (2) Random fiber orientation, (3) Fiber-removed sections.
- Discussion:
 - How do different fiber alignments affect strength and deformation?
 - How might this be represented in a finite element model?

Day 3: Defining Boundary Conditions and Meshing Considerations

Objective:

Students will identify appropriate boundary conditions and discuss how different fiber orientations influence meshing strategies in FEA.

Activities:

- Small-group brainstorming:
 - What constraints (e.g., fixed supports, loads) should be applied to the bridge section models?
 - What should be the loading conditions to simulate real-world stress scenarios?
- Class discussion:
 - How might the fiber orientation change meshing requirements?
 - What kind of elements might be more appropriate for each material structure?
- Instructor guidance:
 - Introduction to types of mesh (structured vs. unstructured) and refinement.

Day 4: Running Simulations in Abaqus

Objective:

Students will simulate bridge section behavior using pre-generated meshes in Abaqus and observe the computational modeling process.

Activities:

- Instructor walkthrough:
 - How to load models in Abaqus.
 - How to apply boundary conditions and materials.
 - How to run a basic simulation.
- Student activity:
 - Students run simulations using provided meshes and compare deformation, stress distributions, and failure points for each fiber orientation.
- Troubleshooting session:
 - Address common simulation errors and interpretation challenges.

Day 5: Interpreting and Communicating Results**Objective:**

Students will analyze and interpret simulation results to evaluate how fiber orientation affects structural performance.

Activities:

- Data analysis:
 - Students review stress-strain plots, deformation results, and compare simulation outcomes across groups.
- Guided questions:
 - What trends did you observe?
 - How did fiber orientation affect performance?
 - Were the results what you expected based on physical models?
- Presentation prep:
 - Each group prepares a short presentation or poster summarizing their results.
- Post-Lesson Google Form