Teacher: Andrew Phillips **Date:** 11/11/13 – 11/13/13 **Class:** IB Physics SL

Topic: Structural Engineering, Newton's Laws and Cumulative Application of Dynamics

Purpose or Goal: To apply Newton's Laws of Dynamics to realia scenarios involving construction and framing.

Major Concepts: Force is a push and/or a pull on an object. Newton's first law states an object at rest tends to stay at rest and an object in motion tends to stay in motion unless acted on by a non-zero net force. A non-zero net force affects an object's ability to maintain its motion in the same way, creating an acceleration. The relationship between force, acceleration, and mass can be defined as Fnet=ma. Newton's third law states forces are paired and for each force there is an equal and opposite force.

Guiding Question: How do we design a building structure to support live and dead loads by applying Newton's laws?

Student Performance Objectives: As a result of this lesson, students will be able to:

- recall the definition of force.
- draw free body diagrams for multiple interacting objects
- formulate a model to quantify the relationship between F, m, and a as Fnet=ma.
- describe paired forces
- draw paired forces on free body diagrams.
- Calculate dead loads based on weights of materials
- Determine necessary force bearing capacity of footings in buildings.

Standards:

- Students know how to solve problems that involve constant speed and average speed.
- Students know that when forces are balanced, no acceleration occurs; thus an object continues to move at a constant speed or stays at rest (Newton's first law)
- Students know how to apply the law F = ma to solve one-dimensional motion problems that involve constant forces (Newton's second law)
- Students know that when one object exerts a force on a second object, the second object always exerts a force of equal magnitude and in the opposite direction (Newton's Third Law).

Activity

Review of Newton's Laws

- Provide students with a novel scenario to reinforce/review Newton's laws of motion
  - Basketball player jumping off the ground for a slam dunk
  - Free body diagrams (FBDs) for during jump, while in the air, while landing

- Have students discuss responses and confer to come to class consensus on correct FBDs

Introduction to application in framing/construction

- Introduce concept of framing/construction
  - Describe what framing is
  - Have students discuss ideas that structural engineers need to consider when designing the building
    - Primary concern is stability
    - Other possible ideas include aesthetics and costs
  - When discussing stability what types of forces does a structure need to withstand?
    - Vertical weight forces of the structure itself (denote this as "dead load")
    - Vertical weight forces of other things within the structure – people, furniture, appliances, etc (denote this as "live load")
    - Horizontal or "shear" forces from natural effects (ie earthquakes, etc)

Discuss properties of framing

- Floors, walls, etc need to be supported by vertical beams called "struts"
- Evenly spaced beams would be structurally ideal (why?)
  - What are the drawbacks of this idea?
    - No space for walking around, furniture, etc. NO OPEN SPACES
- As a result, weight above an open space must be distributed to struts or beams in the walls
- For windows/doorways/etc these loads must be distributed across load dispersing horizontal beams over the open space
- Therefore, it becomes essential to be able to calculate the load that each of these beams/struts will have to support in order to design a structurally sound building frame.

Apply understanding of Newton's Laws to sample problem

- Sample problem (simplified)
  - A one story shed is being built. The shed will consist of one room, size 3mx3m. The room will have ONE supportive beam that will be placed horizontally across the center of the room. This beam is supported by two vertical beams, one at each end of the horizontal beam. The roof has a total mass of 170kg.
  - Students determine the net force on the roof, beam, and struts.
  - Students draw a FBD for the roof, beam, and each strut.
  - Using Newton's Laws, Students calculate the total load that each vertical strut needs to be able to handle.

Maximum Load Capacity

- Extend students' understanding by analyzing provided blueprints.
- Provide students with a sample wall blueprint from Production Framing
- Provide students with a data table describing wood types, lengths, dimensions, and maximum load capacity.

- Students combine their understanding of framing design to identify the "weak points" in the wall.
- From this, students combine data to determine what the maximum carrying capacity of the given wall would be.
- Extension questions:
  - If the type of wood is changed, how might this affect carrying capacity?

Industrial Applications/Assessment

- Divide students into 2 groups.
- Students are tasked with building a two-story storage unit. Each story needs to have 10 foot ceilings and 64 square feet of storage space. The roof of the storage unit will have a weight of 300 lbs. Using ONLY 2x4 lumber, students must design a frame capable of handling a live load of *at least* 1000 lbs on each story.
- Students will present their designs and provide feedback for each other along the way.

Cost Efficiency

- One primary concern when building a structure is cost
- What would the soundest/strongest wall look like? (SOLID, STEEL, REINFORCED, THICK, etc)
  - What are the drawbacks to this structure?
    - Examples: labor intensive, no room for plumbing/electrical, EXPENSIVE
  - Structural engineers/framers need to make money too!
    - Cost efficiency is essential
- Application
  - Provide students with a structural example:
    - 2 story house with attic
    - Ceramic tile roof – slant at 45 degrees
    - Lightweight siding on walls
    - Standard live load on floors
    - Standard storage live load in attic
    - Snowy location – must be able to support snow load
    - 40 ft x 40 ft building
    - 10 ft ceilings
  - Have students draw FBDs and determine the total load (live and dead loads) of the structure
  - Provide students with tables describing load capacity for different lumber (ie 4x4, 6x6, etc) and lengths (4ft, 6ft, 8ft, 10ft, 12ft).
  - Provide students with tables describing average lumber costs (ie cost of 4x4 at 10 ft)
  - Knowing that the structure needs *at least* (possibly more than) 4 struts to stand on, what is the most cost-effective combination of struts that can support the structure?
  - Students work in pairs to determine based on max load capacity and cost
  - Students present and discuss results

Assessment Strategies: Students will write solutions to problems on whiteboards and show to teacher. Students will respond to formative oral questions throughout the lecture. Students will respond to questions, draw FBDs, and do calculations on whiteboards and transcribe them to their papers. Students will complete a building frame design with calculations and submit for assessment.

Adaptations for EL/Special Needs: Discuss action/reaction - use other real world examples of action and reaction to discuss how they relate. Write instructions and definitions on the board for students. Utilize visual representations of material to reinforce conversations. Use laymen terms to explain academic vocabulary.

Materials: Photos of building sites, blueprints, internet access, Cambridge carrying capacity calculation website, load capacity tables, lumber cost tables.

Safety: NA.