Hypersonics and Newton's 2nd Law

Companion Lesson to X-STEM All Access Episode "Disruptive Tech and the Future Workforce"

Grade/ Grade Band: MS/HS	**Topic**: Hypersonic Flight and Newton's Second Law of Motion

Brief Lesson Description: Students use investigation to derive f=ma and apply it to hypersonic flight.

Performance Expectation(s):

HS-PS2-1. **Analyze data to support the claim that Newton's Second Law of Motion describes the mathematical relationship between the net force on a macroscopic object, its mass, and its acceleration.** [Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force.] [Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.]

MS-PS2-2: **Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.** [Clarification Statement: Emphasis is on balanced (Newton's First Law) and unbalanced forces in a system, qualitative comparisons of forces, mass and changes in motion (Newton's Second Law), frame of reference, and specification of units.] [*Assessment Boundary: Assessment is limited to forces and changes in motion in one dimension in an inertial reference frame and to change in one variable at a time. Assessment does not include the use of trigonometry.*]

Specific Learning Outcomes:

Students will:

1. Understand Newton's Second Law of Motion.
2. Conduct experiments to collect data on force, mass, and acceleration.
3. Analyze data to establish the relationship described by Newton's Second Law.
4. Apply the principles of Newton's Second Law to the context of hypersonic flight.

Narrative / Background Information

Prior Student Knowledge:

Students should have a ***basic*** understanding of Newton's First Law (inertia), Second Law (relationship between force, mass, and acceleration), and Third Law (action-reaction pairs). Additionally, students should have measurement skills (including distance, force, and time) and mathematical skills (graphing, solving equations and calculating averages).

Science & Engineering Practices:	Disciplinary Core Ideas:	Crosscutting Concepts:
Planning and Carrying Out Investigations Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim. (MSPS2-2) **Analyzing and Interpreting Data** Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (HSPS2-1) **Connections to the Nature of Science** **Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** Laws are statements or descriptions of the relationships among observable phenomena (HSPS2-1) **Scientific Knowledge is Based on Empirical Evidence** Science knowledge is based upon logical and conceptual connections between evidence and explanations. (MS-PS2-2)	**PS2.A: Forces and Motion** Newton's Second Law accurately predicts changes in the motion of macroscopic objects. (HS-PS2-1) The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. (MS-PS2-2) All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. To share information with other people, these choices must also be shared. (MS-PS2-2)	**Cause and Effect** Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS2- 1) **Stability and Change** Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales. (MS-PS2-2)

Possible Preconceptions/Misconceptions:

Students may bring any of the following preconceptions/misconceptions to this topic that should be addressed throughout the lesson:

1. Force is the same as velocity.
2. Heavier objects will fall faster.
3. Objects need a constant force to maintain motion.
4. All objects accelerate at the same rate. (In previous grades, students may have learned that objects accelerate due to gravity at 9.8 m/s^2 causing this misconception that it applies to all motion)
5. Acceleration and velocity are the same
6. Objects with more mass have more force regardless of acceleration.

LESSON PLAN – 5-E Model

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

1. Begin the lesson by showing the X-STEM Video "Disruptive Tech and the Future Workforce" featuring Dr. Aprille Ericsson. As students watch the video, have them consider the following prompts:
   What types of motion does Dr. Ericsson research and design for her job?
   What are hypersonics? Why is this type of motion investigated by NASA and the Department of Defense?

2. Next, show a short video or animation of hypersonic flight (aircraft traveling at speeds greater than Mach 5). Discuss the importance of hypersonic flight for the Department of Defense, including speed and efficiency in military operations. (Videos for North American X15, Boeing X51 Waverider, or Russian Avengard missile)

3. Discuss the importance of hypersonic flight for the Department of Defense, including speed and efficiency in military operations. Discuss the following prompts:
   "What forces do you think act on a hypersonic aircraft, and how do these forces affect its motion?"
   "How might the mass of the aircraft influence its acceleration during hypersonic flight?"

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

Teachers will determine if they want to complete Option 1 (Non-technology option) or Option 2 (Pocket Lab Voyager Option) for this portion of the lesson.

Option 1: Non-Technology Option

Setup: Divide students into small groups. Each group gets a set of different masses (e.g., small weights), a spring scale, a measuring tape or meter stick, and a stopwatch.

Procedure:
Step 1: Measure the mass of each weight and record it in your lab notebook.
Step 2: Attach the spring scale to each weight to measure the force applied.
Step 3: Set up a straight, flat track on a table or floor for the weights to travel along. Mark a starting line and a finish line 1 meter apart.
Step 4: Apply a constant force using the spring scale to pull each weight along the track. Use the stopwatch to measure the time it takes for each weight to travel the 1-meter distance. Record the force applied and the time taken for each trial.
Step 5: Calculate the acceleration using the formula $acceleration = \frac{2d}{t^2}$ where d is the distance traveled (1 m) and t is the time taken.
Step 6: Repeat the process with different weights and record the force and the time taken for each trial.

Data Recording: Create a table to record the applied force (N), total mass (kg), time (s), and calculated acceleration (m/s^2) for each trial.

Option 2: Option utilizing PocketLab Voyager 2 Sensor

Setup: Divide students into small groups. Each group gets a dynamics cart, different masses, a spring scale, and a PockeLab Voyager.

Procedure:
Step 1: Measure the mass of the empty cart and record it.
Step 2: Attach the spring scale to the cart to measure the force applied.
Step 3: Apply a constant force using the spring scale and measure the cart's acceleration using the PocketLab Voyager accelerometer.
Step 4: Repeat the process by adding different masses to the cart and record the force and resulting acceleration each time.

Data Recording: Create a table to record the applied force (N), total mass (kg), time (s), and calculated acceleration (m/s^2) for each trial.

EXPLAIN:

1. **Data Analysis:**
    - Instruct students to plot their data on graph paper or using graphing software such as Desmos.
    - **Graph 1:** Plot Force (F) vs. Acceleration (a).
    - **Graph 2:** Plot Mass (m) vs. Acceleration (a).

2. **Discussion:**
    - **Graph 1 Analysis:** Discuss the linear relationship between force and acceleration, showing $F=m$. Explain how the slope represents the mass of the object.
    - **Graph 2 Analysis:** Discuss the inverse relationship between mass and acceleration for a given force, reinforcing $a=Fm$.
3. **Real-World Connection:**
    - Relate the experimental findings to the forces acting on a hypersonic aircraft. Discuss how engineers must consider these relationships when designing and testing such vehicles.

ELABORATE: Applications and Extensions:

Scenario Analysis:
Provide students with a hypothetical scenario where they are engineers tasked with designing a hypersonic vehicle.
Prompt: ***"If your hypersonic aircraft has a mass of 2000 kg and you need it to accelerate at 50 m/s^2, what net force must be applied?"***

Group Activity:
Have students work in groups to calculate the required force using $F=ma$.
Discuss how changing the mass of the aircraft or the desired acceleration would impact the required force.

Engineering Challenges:
Discuss the challenges in achieving and maintaining hypersonic speeds, including the forces involved and the importance of balancing mass and acceleration.

EVALUATE:

Formative Monitoring (Questioning / Discussion):
Questions throughout the lesson in ***bold and italics*** can be used to check students' understanding throughout the lesson. You can also assess student understanding through participation and accuracy during the experiment, Quality of data collection and analysis, and Completion of group activities and scenario analysis.

Summative Assessment (Quiz / Project / Report):
Quiz: Provide a short quiz with problems involving different scenarios requiring the use of $F=ma$. This Quizizz is one example.
Reflection: Prompt students to write a short reflection on how understanding Newton's Second Law is crucial in the context of hypersonic flight and other real-world applications.

Elaborate Further / Reflect: Enrichment

Hypothetical Hypersonic Aircraft Design Challenge
Objective: Apply knowledge of Newton's Second Law to design a hypothetical hypersonic aircraft.
Instructions:

1. **Research Phase:**
    - Assign students to research existing hypersonic aircraft designs and the principles of aerodynamics and propulsion that govern their operation.
    - Have them identify key factors such as mass, thrust, and drag, and how these relate to Newton's Second Law.
2. **Design Phase:**
    - Divide students into small groups and challenge them to design their own hypothetical hypersonic aircraft using their understanding of force, mass, and acceleration.
    - Students should consider how to optimize the aircraft's shape, propulsion system, and materials to achieve maximum speed and efficiency.
3. **Presentation:**
    - Each group presents their aircraft design, explaining how Newton's Second Law influences their design choices.
    - Encourage peer evaluation and discussion on the feasibility and innovation of each design.

SOCIAL EMOTIONAL LEARNING ACTIVITY

CASEL Competency Addressed: Relationship Skills

During the X-STEM Video, Dr. Ericsson discussed how NASA and the Department of Defense would benefit from collaboration on hypersonic flight. As a STEM student, you too can benefit from collaboration. This lesson will help students to analyze their collaboration during this lesson and set goals to improve these skills.

Introduction

1. **Warm-Up Activity:**
    - Begin with a brief discussion about the importance of collaboration in various aspects of life, including school, work, and personal relationships. One possible prompt is: ***"Why is effective collaboration important? Can you think of a situation where good or bad collaboration had a significant impact?"***

Evaluating Collaboration

1. **Individual Reflection:**
    - Hand out reflection sheets and ask students to reflect individually on their recent group work experience during the physics experiment.
    - Reflection Questions:
        - ***Was the collaboration in your group generally positive or negative? Why?***
        - ***Which collaboration skills did you and your group members use effectively?***
        - ***Were there any challenges or conflicts in your group? How were they handled?***
        - ***How did the group dynamics impact the outcome of the experiment?***
2. **Group Evaluation:**
    - Provide group evaluation forms for each group to fill out together. This encourages them to discuss their experiences and come to a consensus on the overall effectiveness of their collaboration.
    - Evaluation Criteria:
        - ***Communication: Did group members communicate clearly and respectfully?***
        - ***Participation: Did everyone contribute equally to the tasks?***
        - ***Problem-Solving: How well did the group handle any issues or conflicts that arose?***
        - ***Support: Did group members support each other and work towards common goals?***

Group Discussion and Brainstorming

1. **Class Discussion:**
    - Gather the class together to share some of their reflections and evaluations. Use a whiteboard to list common positive aspects and challenges mentioned by the groups. One possible prompt includes: ***"Based on your reflections, what were some of the strengths and weaknesses in your group collaborations?"***
2. **Brainstorming Session:**
    - On chart paper, create two columns: "Challenges" and "Improvement Strategies."
    - Divide students into small groups and provide them with sticky notes. Ask each group to brainstorm and write down one or two collaboration challenges they faced.
    - Once all groups have contributed their sticky notes to the "Challenges" column, ask them to brainstorm potential strategies to address these challenges and write them down for the "Improvement Strategies" column.
    - Examples of Challenges and Strategies:
        - **Challenge:** Unequal participation/ **Strategy:** Assign specific roles and responsibilities to each group member.
        - **Challenge:** Poor communication/ **Strategy:** Implement regular check-ins and active listening techniques.

Action Plan Development

1. **Creating Action Plans:**
    - Have each group select two or three improvement strategies from the brainstorming session that they believe would be most effective for their next group activity.
    - Provide action plan templates for each group to fill out, outlining specific steps they will take to implement these strategies.
    - Action Plan Template:
        - **Challenge:** [e.g., Unequal participation]
        - **Strategy:** [e.g., Assign specific roles]
        - **Steps to Implement:**
            - Step 1: Discuss and agree on roles before starting the activity.
            - Step 2: Rotate roles in each session to ensure everyone gains experience.
            - Step 3: Check-in periodically to ensure roles are being followed.

2. **Group Presentations:**
   - Have each group briefly present their action plan to the class. This allows for sharing of ideas and fosters a collective commitment to improving collaboration.

Conclusion and Commitment

1. **Class Commitment:**
   - Facilitate a class discussion on the importance of committing to their action plans and continuously working to improve collaboration skills using the prompt: ***"What is one specific thing you will personally commit to doing to improve our group's collaboration next time?"***
2. **Personal Goals:**
   - Ask students to set a personal goal related to collaboration that they will focus on during the next group activity. Have them write down their goals and keep them in a place where they can review them before the next activity.
   - Example Personal Goal:
     - "I will actively listen to my group members by making eye contact and summarizing what they say before adding my own thoughts."

INTERDISCIPLINARY CONNECTIONS/IDEAS

Language Arts: Organize a debate where students argue the ethical considerations of developing hypersonic aircraft. Topics could include environmental impact, military applications, and international relations, grounded in the principles of Newtonian physics.

Social Studies: Analyze the geopolitical impact of hypersonic flight technology on global power dynamics. Consider how countries' investments in research and development are shaped by Newtonian principles of force, mass, and acceleration.

Physical Education: Relate fitness activities (e.g., sprinting, jumping) to Newton's Second Law by measuring acceleration. Discuss how athletes can improve performance by understanding and applying these principles of force and motion.

Computer Science: Have students develop computer simulations or animations using coding platforms (e.g., Python, Unity) to model hypersonic flight dynamics. They can program scenarios that demonstrate the relationships between forces, mass, and acceleration.

Materials Required for This Lesson/Activity

Quantity	Description
Option 1: Non-Technology Option	
1 per group	Set of small weights
1 per group	Spring Scale
1 per group	Measuring Tape or Meter Stick
1 per group	Stopwatch
Option 2: Pocket Lab Option	
1 per group	Dynamics Cart
1 per group	Set of small weights
1 per group	Spring Scale
1 per group	PocketLab Voyager

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