Linear and Rotation Mechanisms: Analyzing Behaviors of Mechanical Systems

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Grade Level: 7-8  Time Required: 3, 60 minute sessions

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Summary
In this lesson the students will be introduced to forces, torques, and how those concepts apply to creating linear and rotational motions. The lesson first introduces concepts such as forces and torques which are built upon to teach more in depth concepts such as free body diagrams (FBDs), and linear and angular motions due to net forces. This lesson incorporates lectures, demonstrations of concepts, and activities in order to reinforce the important and major details of the topics.

Learning Objectives
- Understand Newton’s three laws of motion
- Understand the differences between forces and torques
- Understand the relationship between forces and movements
- Apply concepts of forces and torques to analyze behaviors of simple bar linkage systems

Lesson Plan
The lesson is divided into three sessions. In Session 1, Newton’s law of motion will be introduced leading into detailed explanations of forces. Session 2 covers more in depth concepts of such as torques and FBDs. Session 3 takes the knowledge of forces, torques, and explores linear and rotational motions. The lesson involves interactive demonstrations and activities to enforce lesson concepts. Any information and problems to be used in the lectures can be found in a basic physics textbook.

Session 1
Pre-requisites—Students should have completed a course in algebra

Lecture: Newton’s Three Laws of motion

In this lecture Newton’s three laws of motion should be taught. The equations for should be introduced to the students so that they can interpret the meaning of the equation and are able to apply it to simple situations and examples. The types of forces such as applied, reaction, normal, weights, friction, etc. should be discussed and understood. After this lecture students
should be able to understand the three laws of motion and understand various types of forces and their behaviors in the environment.

*Activity 1: Newton’s First Law*

Materials: a bottle of water, a sheet of paper (8.5” x 11” or larger)

In order to demonstrate Newton’s first law, have each student place a piece of paper at the edge of their desk or a flat surface so half of the sheet of paper hangs off the edge. Then have the students place a water bottle on the table on top of the sheet of paper. First have the students slowly pull on the paper and observe the bottle of water move along with the paper. Then instruct the students to quickly pull the sheet of paper out underneath the bottle of water while creating the least amount of movement in the bottle (Note: Pulling at a downwards angle makes this task easier).

After the activity, ask the students, why did the bottle move a lot when pulled slowly and not a lot when pulled quickly? After some discussion explain that the friction force created during the slow movement is greater than the force in the fast movement; therefore, the bottle moves more because a large force acts upon the mass.

*Demonstration 1: Newton’s Second Law*

Materials: plastic bat, baseball, whiffle ball

In order to demonstrate Newton’s second law, first remind the students that a net force is required for a mass to accelerate. First demonstrate that if there is no net force a mass will not accelerate; place one of the balls against a wall and tap it with the bat. Explain that the wall provides an equal and opposite reaction force when being tapped by the bat resulting in no net force.

Then tap the baseball when it is not against the wall and observe the ball accelerate. Explain that there is no longer a wall to provide a reaction force; the ball experiences a net force causing acceleration. Finally, tap the whiffle ball with about the same amount of force and observe the larger acceleration. Ask the students why the whiffle ball moved faster than the baseball when the same net force was applied; have the students relate their explanation mathematically to the equation \( F = ma \).

*Demonstration 2: Newton’s Third Law*

Materials: chair with wheels, 5 pound medicine ball

In order to demonstrate Newton’s third law, sit on a chair that can roll along the ground while holding the 5 pound medicine ball. Then toss the ball and have the students observe the motions; the ball accelerating in one direction while you in the chair move in the opposite direction. Ask the students why the ball and you in the chair moved in opposite directions. Also ask why the ball moved farther than you in the chair. Explain to the students that both you in the chair and the ball experienced the same force in opposite direction when the ball was tossed. Because the ball has less mass, it accelerated further. Again use the equation \( F = ma \) to explain the concepts.
Session 2

Pre-requisites: Session 1, Lecture: Newton’s Three Laws of Motion

Lecture: Torques and FBDs

In this lecture, the concepts learned in the previous session will be built upon. Introduce torques to the students by explaining that they are simply forces applied at distances. Explain the similarities between forces and torques. Relate torques back into Newton’s laws and explain how Newton’s laws apply to rotational systems with torques. Torques should be introduced to the students similarly to how forces were covered in the previous lecture. The procedure of producing FBDs should be covered during this lecture. Multiple examples of FBDs should be used to help understand and introduce accelerating bodies, linear, and rotational motions. At the end of the lecture, the students should understand the procedure to create FBDs and the concepts of torques.

Demonstration 3: Applied Torques

To get a better understanding of torques, push on a door at different distances from the hinge. Encourage students to try the same. Have the students observe that it requires more force to swing/rotate the door at a shorter distance from the door. Discuss why, it’s easier to open a door the farther you place the force and relate back to the equation for torques, rotational motion, and Newton’s laws.

Activity 2: Creating FBDs of Familiar Objects

At the end of the lecture, encourage the students to walk around the room in small groups or pairs, and find objects to create a FBD. Have the students start with simple situations such as an eraser resting on a desk or a notebook leaning on a surface to create free bodies. Then encourage the students to visualize their objects in other common situations where a more complicated FBD exists. For example, holding a pencil or erasing pencil marks. Allow the groups or pairs to discuss what forces exist on the free bodies and if time allows, have each group share their FBDs with the class.

Session 3

Pre-requisites: Session 2, Lecture: Torques and FBDs

Lecture: Linear and Rotational Motions

By applying the force and torque equations, the students should learn to apply the equations to FBDs to analyze linear and rotational motions. Simple analysis of FBDs and calculations of linear and angular accelerations should be covered in this lecture. Depending on the student feedback, go into more complicated situations or problems solving for different variables rather than accelerations. At the end of the lecture, the students should have a basic understanding of how forces and torques relate to linear and angular accelerations.
Activity 3: Linear and Rotational Motions of Bar Linkages

Materials: Scissors, construction paper, paper fasteners

To help visualize linear and rotational motions, the students will create different bar linkages where they will be able to physically manipulate the linkages to observe motions. First, have the students cut out slim rectangles out of construction paper in various lengths, some with the same lengths. Then have the students pin on one link on a piece of paper with a fastener, the location or orientation of the fastener is irrelevant so long as the link is fixed on the paper. Have the students then manipulate the single link to observe the movements. Discuss the forces the link is experiencing and the motions associated with those forces.

Then allow the students to create more complicated linkage systems in any way they choose; the students can connect linkages together, fix another link to the paper, or both. Allow them to experiment with multiple designs and observe the movement behaviors of all designs. Suggest to the students to manipulate the system with one hand first then with two to observe any differences. Again discuss the forces the links and system are experiencing and how they are creating the observed motions.

Wisconsin academic standards covered in this lesson

TE.BB1.c.2.m: Explain the relationship between the inputs and outputs of linear, rotary and compound motion mechanism in terms of direction, distance, and force.

TE.BB1.c.3.m: Define mechanical concepts such as force, work, power, torque, velocity, mechanical advantage, and gear ratio.

TE.BB1.c.4.h: Build, test, and trouble shoot simple linear, rotary, and compound mechanisms.