Lesson Title: The Physics of Soccer

Abstract:
In this lesson plan, students will engage in embodied education by combining physics principles with soccer. Through a hands-on approach, students will explore the laws of motion, gravitational forces, and energy transfer as they actively participate in soccer drills. By connecting theoretical concepts to real-world scenarios on the soccer field, students will gain a deeper understanding of physics and its practical applications. This learning approach not only enhances their comprehension of scientific principles but also fosters teamwork, critical thinking, and a genuine enthusiasm for learning as they kick, pass, and score their way through the fascinating intersection of physics and soccer.

Keywords:
Physics, Highschool, Soccer, Projectile Motion

Goal(s):
Teach students a little bit about soccer while also conveying some of the physics that goes into the sport.

Learning Objectives

- Learn how to kick a soccer ball properly
- How the force exerted by the foot transfers energy to the ball (Force and energy) ● The role of the player's mass and peed in the momentum is transferred(Momentum) ● Trajectories of different kicks
- Learn about the arc of a soccer ball in the air in terms of projectile motion ● Show how the different ways to kick a soccer ball lead to different paths

Assessment
Instructor should be checking for understanding throughout the lesson. Preferably in between every different shot that the students practice. The end of the class should be devoted to discussing key questions provided in a handout to the student (handout at the end of document).

Purpose/Rationale
The reason we're teaching this lesson is because it's a cool and interesting way for students to learn physics. Instead of just reading about it, they get to play soccer and see how physics works in real life. The important part is that it helps them understand how physics is useful in everyday situations, not just in textbooks. This way of teaching also makes sure students really get what they're learning because they're doing things, not just listening. It's like learning by playing, making the whole experience more interesting and memorable.

Prior Preparation
The beauty of this lesson is in its simplicity. While it would be beneficial for the instructor to be knowledgeable in soccer so that live demonstrations are available to the students, nothing else is necessary except for proper sport attire and good weather. There is a handout at the end of

this document that could be used as supplemental questions.

Materials/Resources

This lesson is beneficial in the fact that it only needs a limited amount of supplies that can be easily gathered by almost anyone.

- Soccer balls (number depends on the size of the class)
- Open field (preferably with soccer goals)

Bibliography/Resources

- https://www.gearssports.com/articles/how-to-kick-a-soccer-ball/
- Football physics: The "impossible" free kick - Erez Garty

Rough Outline of Lesson

- Explain what are about to do
- Different techniques of kicking the ball
- Talk about the human body's role in soccer techniques
- How far and accurate you can hit the ball

Info on the different types of shots

Standard Shot:

The standard shot in soccer is executed using the area around the knuckle of the foot. This technique balances power and control, making it ideal for players in multiple positions on the field.

Straight Shot:

This shot is executed using the area around the shoe laces, often referred to as the "instep". A straight shot is characterized by its power and direct trajectory towards the goal.

Inside Shot:

The inside shot utilizes the inside part of the foot, offering greater control and precision. This technique is particularly effective for passing, shooting with accuracy, and maintaining possession in tight spaces. The inside part area of the foot provides a larger surface for contact, enabling more precise direction and speed control.

Outside Shot:
The outside shot is executed with the outside of the foot and is used to create a curvy trajectory, often bending the ball around defenders or the goalkeeper.

Toe Shot:
The toe shot is executed when the player uses the toes of their foot to strike the ball. It is generally recommended due to its lack of control and precision.

Soccer Physics Concept Questions

1. **How do Newton's laws of motion apply to a soccer game? Provide specific examples for each law.**

2. **Explain the role of friction in soccer. How does the type of playing surface (grass vs. turf) impact the game in terms of friction?**

3. **Explain why the toe shot is inaccurate.**

4. **Discuss the concept of collisions in soccer. How do the masses and velocities of players and the ball affect the outcomes of collisions?**

5. **Discuss how the principle of conservation of momentum applies to interactions between players and the ball in a soccer match.**

6. **Describe the Magnus effect and how it is relevant in soccer. How does a player putting spin on the ball affect its trajectory?**

- **Projectile Motion**
  - Calculate the arc of a soccer ball in the air
  - Students can record the angle and speed of the ball and predict where it will land using the equations of motion
- **Force and Energy**
  - Have students measure the force applied to a soccer ball at different inflation levels to understand the relationship between force, pressure, and volume

- **Momentum and Collisions**
  - Use soccer balls like billiards to analyze elastic and nonelastic collisions. Students can calculate the momentum before and after the collision and discuss conservation laws.

1. Types of Shots and Corresponding Foot Areas:

- Standard Shot: Utilize the area around the knuckle of your big toe.
- Straight Shot**: Use the area around your shoe laces. (powerful)
- Inside Shot: Kick with the inside of your foot. (straight)
- Outside Shot**: Use the outside of your foot. (curvy)
- Toe Shot**: Use the toes of your foot(not recommended)
- How to Kick a Soccer Ball: 10 Steps to the Perfect Kick - Gears Sports](https://www.gearssports.com/articles/how-to-kick-a-soccer-ball/).

2. Controlling Ball Trajectory: - The point of contact on the foot, combined with foot orientation and swing, determines the angle of attack and subsequent ball trajectory. This affects whether the ball follows a straight, curved, or knuckle-ball path.

- For a straight trajectory, the impact should be close to the ball's center. ● For a curve, aim closer to the ball's near side,
- and for a knuckleball, aim towards the far side.
- Applying Spin: When executing free kicks, corner kicks, and other shots, players apply spin to the ball during contact, which influences its curve.
  - For a right-footed player, a natural technique involves brushing toward the outside of the ball, creating a right-to-left hook, while a left-footed player’s shot naturally curves left-to-right in play.

The physics behind soccer shots and ball trajectories involves several fundamental

principles:

1. **Conservation of Energy**: Energy is transferred from the player to the ball, causing various types of movement. This principle states that energy cannot be created or destroyed, only transformed from one form to another

2. **Newton's First Law of Motion**: A stationary ball remains still until a force is applied, and a moving ball continues in motion unless acted upon by an opposing force. This law is crucial in understanding how a soccer ball starts and stops moving

3. **Force, Angle of Force, and Air Resistance**: The force a player applies to the ball determines its speed and direction, while the angle of force affects its trajectory. Air resistance (drag) also significantly impacts the ball's movement, depending on the ball's velocity, surface area, and air density.

4. **Gravity**: Gravity pulls the ball towards the earth's center, influencing its trajectory. The speed, angle, and direction of the kick determine whether the ball follows a straight path or a curved one due to gravity's pull

5. **Magnus Effect:** When a ball is kicked off-center, it spins, causing a curve in its flight path. This effect is due to friction between the ball and air, where the air velocity around the ball changes depending on the direction of the ball's spin. For example, a ball kicked right of center will spin counter-clockwise, causing it to curve left, and vice versa

6. **Inelastic Collision and Coefficient of Restitution**: Kicking can be analyzed as an inelastic collision between the ball and foot. The coefficient of restitution (e) is crucial here, as it measures the efficiency of energy transfer during the collision. A higher coefficient means a more efficient kick and higher ball speed. This coefficient depends on factors like the ball's and shoe's mechanical properties, ball temperature, and the player's foot and ankle during impact

7. **Impulse and Kick Force:** The impulse equation ($F_{avg}\Delta t = m_{b}\Delta V_{b}$) can be used to estimate the kick force generated by a player. This equation considers the average kick force during impact, the duration of impact, and the change in ball velocity. For instance, a professional soccer player can exert a kick force of approximately 1350 N