**Unit 1 – Forces in 1D (Instructor Narrative)**

Engineering Statics in Physics Project

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**1.1 Forces push and pull**

A stretched bungee cord and a squeezed volley ball will be used to exemplify simple “pulls” and “pushes” that can be felt. The strength and direction of these forces will be identified and discussed with students.

LEARNING OBJECTIVE: Students will be able to identify the forces associated with bodies in physical contact and to use vector notation to represent these forces.

**Class Demonstration and Discussion**

Rest a bungee cord on a table with the left end of the bungee cord hooked around an object that prevents it from moving. Use your finger to pull on the right hook: first stretching the bungee a short distance and then stretching it a longer distance. Describe how your finger feels in the two instances.

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The bungee cord pulls on your finger and your finger pulls on the bungee cord. Your finger and the bungee cord exert forces on each other. A force is always between two bodies. The forces act oppositely: your finger pulls the hook to the right, and the hook pulls your finger to the left. The longer you stretch the bungee cord, the greater you feel its pull on your finger. These opposing forces have the same intensity or magnitude. In other words, two contacting bodies exert equal and opposite forces on each other.

Next, loop your finger around the right hook and, keeping your finger in one place, have a second person grab the left end of the cord and pull it so the cord gets longer. Again, notice the force you feel on your finger from the hook. If the cord stretches to the same length, your finger feels the same force as it did before. It does not matter if your finger did the moving or the other end was moved and your finger stayed in position. Force is the pulling *sensation* on your finger. It is not directly related to whether your finger moved or not.

Draw an arrow on the finger (shown below) to represent the force of the hook on the finger. The arrow should point in the direction that the hook pulls on the finger. Next, draw an arrow on the hook to represent the force of the finger on the hook. The arrow should point in the direction that the finger tries to pulls on the hook.



Fcord-hand

Fhand-cord

Since they are of equal magnitude, the two forces (represented by arrows drawn on the picture above) are often designated by the same label (*e.g.* F1).

Place a volley ball on the table and have two people push on the ball as shown.

The left hand pushes on the ball (to the right) and feels a push from the ball (to the left). On the picture below, draw an arrow to represent the force of the hand on the ball and an oppositely directed arrow for the force of the ball on the hand. We can label those equal and opposite forces as F1.

Now draw arrows to represent the pair of forces between the ball and the right hand. We could label those equal and opposite forces as F2.

If the ball is not moving, the forces F1 and F2 have the same magnitude. If only one hand pushed, or the hands pushed by different amounts (giving F1 and F2 different magnitudes), then the ball would move. We will consider this situation next.

*SEE ACTIVITIES IN STUDENT WORKSHEET*

**1.2 Forces can change motion**

Two balls and a mallet will be used to demonstrate three important principles of force and motion: (i) acceleration is in the direction of the applied force, (ii) the amount of acceleration is directly proportional to amount of force applied and inversely proportional to the amount of mass accelerated, and (iii) acceleration caused by multiple simultaneously applied forces is aligned with and proportional to the net vector sum of these forces.

LEARNING OBJECTIVE: Students will be able to associate the change in velocity (*i.e*. acceleration) of a ball with an applied force. They will learn to correlate the magnitude and direction of this acceleration with: 1) the vector sum of contributing forces and 2) the amount of mass being moved.

**Class Demonstration and Discussion**

**(i) acceleration is in direction of the applied force:** Carefully place a bowling ball on the floor. While one student prevents the bowling ball from striking the walls, have a second student tap gently on the ball with a mallet so it starts to move. Note its speed. Tap again with the mallet on the same side of ball and again note its speed. Each press with the mallet should increase the ball’s speed: it should goes faster in the direction of the mallet’s push or force.

With the ball moving in one direction along the hallway, give a press briefly with a mallet against the bowling ball now opposite to the ball’s motion. Note the change in speed. The ball is still moving in the same direction but more slowly. The force speeds the ball up in the direction of the force, or it slows down the ball opposite to the direction of the force. The direction of the force (the push) can be independent of the direction the ball is moving at the instant.

**(ii) the amount of acceleration is directly proportional to amount of force applied and inversely proportional to the amount of mass accelerated:** Next, push with mallet on a soccer ball and notice that it is easier to change the speed of the soccer ball than the bowling ball. This is because the soccer ball has less mass than the bowling ball.

**(iii) acceleration caused by multiple simultaneously applied forces is aligned with and proportional to the net vector sum of these forces:** Use two mallets to tap on opposite faces of the ball. You can make the ball move one way or the other, depending on which force is larger. If there is a large push on one side, and a slightly larger push on the other side, then ball acts like there was a small push from the side with a larger push. The net effect of the two opposite forces on the ball depends on their difference. Consider the following representations of the forces on the bowling ball:

F1

F2

When multiple forces push on the ball, oppositely directed forces have opposing effects on the ball’s motion. That is, the ball would accelerate to the right if F1 was larger than F2 and it would accelerate to the left if F2 was larger than F1. The ball would not accelerate if F1 and F2 were of equal magnitude. The ball’s acceleration, thus, is determined by the combined force on the ball. This combined force is referred to as the net force and is found from vector addition of the contributing forces.

F2

F1

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**1.3 Earth’s gravitational pull is a force**

Two balls, with different masses, will be used to demonstrate acceleration caused by the force of gravity. This force, designated as the weight, is directed downward and is proportional to an object’s mass, resulting in the same amount of acceleration if no additional forces are considered.

LEARNING OBJECTIVE: Students will be able to recognize the gravitational pull of Earth as an example of a force.

**Class Demonstration and/Discussion**

**(i) the force due to earth’s gravitational pull accelerates a falling body:** Release a tennis ball from successively greater heights. The ball begins its journey with zero speed and moves downward with increasing speed. The greater the height from which the ball is released, the greater the speed at the end of its journey. Thus the falling ball is accelerating.

In the previous activity, it was shown that a force was needed to change the speed of a bowling ball. Likewise, a force is needed to increase the speed of the falling tennis ball. This force is the gravitational force exerted by the Earth on the ball. It is called weight and is often denoted by the letter “W”.

**(ii) the force due to earth’s gravitational pull is proportional to an object’s mass:** Release two balls of different masses from the same height. Notice that they reach the floor at approximately the same time. This is because they have the same acceleration. The acceleration due to gravity is denoted by the letter “g”.

In the previous activity, it was shown that a greater force was required to produce the same acceleration of a more massive body (the bowling ball). In the case of the dropped balls, the more massive ball must experience a greater force since it experienced the same acceleration as the less massive ball.

This picture is consistent with the previous activity. The amount of acceleration (“g”) is directly proportional to the amount of force applied (“W”) and inversely proportional to the amount of mass moved.

**W = g ∙ mass**

In the spirit of the previous activities, we use an arrow to represent draw the force due to gravity on an object.

W

*SEE ACTIVITIES IN STUDENT WORKSHEET*

**1.4 Simple equilibrium – perceptible forces**

Two blocks, of different masses, will be used to help students learn to identify the individual forces acting on a body and to distinguish between a block’s “weight” and the block’s “push” on an outstretched hand. When a body is in equilibrium, it is either stationary or moving at constant speed and the net force on this body is zero. That is, the forces in one direction add up to equal the magnitude of the forces in the opposite direction.

LEARNING OBJECTIVE: Students will be able to create and analyze a free-body diagram that illustrates forces acting on a body in equilibrium.

**Class Demonstration and Discussion**

Rest a small block on your hand and then a large block. Keeping in mind the force(s) experienced by your hand, draw two free-body diagrams (FBD’s): 1) one for the block and 2) one for the hand. Using your FBD’s,

1. explain why your hand experiences more force from the larger block.
2. identify the difference between: 1) the weight of the block and 2) the push from the block on the hand
3. explain why the force of the hand on the block has the same magnitude as the weight of the block

Notice that since the block remains motionless, the force of the hand on the block must equal in magnitude the opposing force due to Earth’s gravitational pull on the block. Next, according to Newton’s 3rd Law, the force of the hand on the block and the force of the block on the hand must be of the same magnitude as well. It follows that the force of the block on the hand must have the same magnitude as the force due to Earth’s gravitational pull on the block.

*SEE ACTIVITIES IN STUDENT WORKSHEET*

**1.5 Equilibrium – less perceptible forces**

Three bridging analogies will be used to help students visualize forces exerted by inert, rigid objects. The process of “bridging” begins with an example in which forces can be identified easily by students. The instructor then employs a series of analogies that are increasingly similar to the system he/she would like the students to understand.

LEARNING OBJECTIVE: Students will be able to identify contact forces exerted by inert rigid objects.

In the previous section, we referred to the force exerted by block on hand – this is an example of rigid, inert body exerting a force. Students might only have found this force exerted by a rigid, inert body acceptable because they mistakenly viewed the force being exerted as the weight force, and weight is a familiar force.

The forces exerted by inert, rigid objects can be rationalized in several ways:

* We “feel” a force exerted on us (on finger) by an object that we believe can exert a force (*e.g.* bungee cord pulled by someone). Since we feel the same thing from an inert, rigid object, that object plausibly can exert a force.
* A force is needed to explain equilibrium given other forces that are known to be present.
* An object can be said to exert a force even if that object is reacting to something else, rather than initiating the interaction.
* Contact between bodies always makes forces between them possible.

**Class Demonstration and Discussion**

**(i) first bridging analogy:** The force of a wall hook on an object attached to it.

Describe the sensation felt by your finger when:

1. your finger pulls on a bungee cord, causing it to stretch.
2. your finger remains stationary but attached to one end of a bungee cord which someone else stretches by pulling.
3. your finger pulls on a wall hook.

So the wall hook can exert a force on an object attached to it.

**(ii) second bridging analogy:** The force of the wall on object that rests against it or bounces against it

Describe the sensation felt when:

1. a book is pressed horizontally against your stationary outstretched hand.
2. your hand presses horizontally against a wall.

1. you lean (tilted) with your hands against the wall.

So the stationary wall can exert a force on an object that rests against it.

Describe the force(s) on a moving ball when:

1. it strikes a paddle that you swing.
2. it strikes a paddle that you hold stationary.
3. it strikes a stationary wall.

So the stationary wall can exert a force on an object that bounces against it.

**(iii) the third bridging analogy**: The force of a table on an object sitting on it.

Describe the forces on an object when:

1. it rests on an outstretched hand.
2. it rests on a squishy foam pillow that sits on the outstretched hand.
3. it rests on a squishy foam pillow that sits on a table.
4. it rests on a table.

So the table can exert a force on an object that rests on it.

*SEE ACTIVITIES IN STUDENT WORKSHEET*