3. FORCES

IF NOTHING ELSE, MY STUDENTS SHOULD LEARN…

1. Force is defined by the interaction between separate objects. The term force is used to describe and measure the interaction. Force has several properties but is mainly characterized by its two quantitative properties: magnitude and direction.

2. There are four fundamental forces in nature: (1) gravity, (2) the electromagnetic force, (3) the strong nuclear force, and (4) the weak nuclear force. These forces are contact-free forces that do not require contact between objects; they are called **field** forces. All other forces are considered to be non-fundamental.

3. Muscle tissue serves the specific purpose of exerting forces; locomotion in turn is achieved when several muscles and other tissues, such as bone, cooperate.

LEARNING OBJECTIVES

Students should be able to:

- Remember that muscles are divided according to form and function into three types: skeletal, smooth, and cardiac. (remember)

- Understand that a force is an interaction between objects, such as a push or pull. (understand)

- Understand that forces can act through direct contact between objects, and these are called contact forces. Examples are the normal force, tension on a string, and friction. (understand)

- Understand that forces can act between objects over great distances without the need for contact. These are called field forces. Examples are gravity and the electric force. (understand)

- Understand that force is a vector, thus it always has a direction and a magnitude. (understand)

- Evaluate the additive nature of forces. The effect of two simultaneous forces on the same object is the same as that of a single force equal to the addition of the forces. The addition is vector addition and the resultant force is called the net force. (evaluate)

- Analyze forces acting on an object, i.e. changes in the velocity of the object. (analyze)

- Understand that a restoring force in one which tends to bring an object back to its initial position, or to a position of equilibrium. An example of such a force is the elastic force of a spring, which always tends to return to its uncompressed or unstretched length when released. (understand)

- Analyze how forces always act in pairs. (analyze)

- Remember that the unit of force is the newton (N). The newton is a derived (SI) unit. In terms of fundamental units, 1 N = 1 kg·s2/m. (remember)

- Remember that the gravitational force of the Earth on any object, is commonly called the object's weight. (remember)

- Solve mathematically the force of gravity between two masses, given by the expression:

$$F = G\frac{m_1 m_2}{r^2},$$

  where m1 and m2 are the masses of the objects, r is the distance between the two objects, and G is the universal gravitational constant 6.674 ×10−11 N · m2/kg2. (apply)

- Understand that "g" is the acceleration of gravity. At the surface of the Earth, it is approximately equal to 9.8 m/s2. It is the quotient of an object's weight and its mass. (understand)

- Determine mathematically the electric or Coulombic force between two charges, given by the expression:

$$F = k\,\frac{q_1 q_2}{r^2},$$

  where q1 and q2 are the magnitudes of the charges of each object (in coulombs, "C"), r is the distance between the two objects, and the constant k is the electric force (or Coulomb) constant and is equal to k = 8.99 × 109 Nm2/C 2. (analyze)

- Remember that the electric force is attractive if the charges are of opposite sign, and it is repulsive otherwise. (remember)

- Remember that the strong force holds protons and neutrons together in the nucleus. Since it overcomes the repulsive electric force, it is the strongest of the fundamental forces, but it has no significant effect outside the atomic nucleus. So the nuclear force is very strong and short-ranged. (remember)

- Remember that the weak force - the last of the four fundamental forces - plays a role in the decay of certain nuclei, and it extremely short-ranged. (remember)

- Classify examples of everyday non-fundamental forces such as the normal force, tension on a cable, the force of a spring, friction, air drag, and others. These forces are all macroscopic manifestations of microscopic electrical forces. (analyze)

- Analyze a free body diagram which is a sketch of all forces acting on an object. It includes the object and vectors representing the applied forces on it. It shows all types of forces, both fundamental and convenience, exerted on the object. (analyze)

- Understand that if the net force that acts on an object is zero, the object is in equilibrium, and the object stays at rest or continues to move without changing its velocity. (understand)

- The mathematical condition for equilibrium is expressed as:

$$\vec{F}_{\text{net}} = \sum_i \vec{F}_i = 0.$$

  where Fi is the ith force acting on the object.

- Remember that the vestibular apparatus in our inner ears are capable of detecting the direction of gravity - and thus - of establishing up and down, independent of visual cues. (remember)

- Remember that our skins are equipped with mechano-receptors capable of indicating the magnitude of forces acting on them. They work by correlating the magnitude of a force with the compression of the skin. (remember)

WHY IS THIS CHAPTER IMPORTANT TO SCIENTISTS?

- The concept of a force as an interaction between two objects is introduced. A classification of forces into **fundamental** and non-fundamental or of **convenience** is introduced. A description of each type of force is presented.

- The properties of forces are introduced, and their vector nature is established. The muscular system as the origin of mechanical forces in the body is presented.

- The **free body diagram** is introduced as a useful analytical tool for solving mechanical problems.

- The concept of mechanical **equilibrium** is introduced. The conditions required to established equilibrium are defined.

WHY SHOULD STUDENTS CARE?

- In this chapter, we introduce qualitatively, the mechanical concept of a **force** as an interaction between objects.

- We distinguish the four known fundamental forces from other everyday forces which are macroscopic manifestations of the electromagnetic force.

- We introduce within the human body, the muscular system as the origin of most mechanical forces. A detailed physiological model for muscle action is presented.

- The basic properties of a force are discussed, along with the vector nature of all forces.

- An introductory description of everyday – or convenience – forces such as tension, friction, normal, and drag forces, is presented.

- The concept of a **free body diagram** is introduced, and its usefulness as an analytical tool is discussed.

- The concept of **mechanical equilibrium**, and its consequences, is analyzed.

- Physiological mechanisms which allow us to keep our balance, and judge the magnitude of external forces acting on our bodies, are discussed.

WHAT ARE COMMON STUDENT MISCONCEPTIONS/STUMBLING BLOCKS?

1. Students can have a difficult time understanding the concept that forces ALWAYS act in pairs. There is no such thing as an isolated, single force acting on an object. When object A exerts a force on object B - whether through contact or through the action of a field (gravitational, electric, or magnetic) - object B exerts an identical force on object A, except for one characteristic: the force is antiparallel. Many examples can be given to substantiate this claim.

2. The concept of equilibrium may cause students some difficulty. If a body is in equilibrium, this does NOT mean there are no forces acting on it! Equilibrium is defined as a mechanical condition in which the NET force acting on an object is vectorially equal to zero, in other words they cancel out. The mechanical effect of this condition is equivalent to having NO force acting on the object, but the two conditions are different. Of course, a condition of equilibrium implies that the velocity of the object remains constant.

3. Friction is a concept that often creates trouble for students. For example, they can have some difficulty comprehending, or accepting, that the force of friction between two bodies is independent of the contact area between them, depending only on the normal forces pressing them together. There may also be some difficulty understanding that static friction is typically larger than sliding friction.

WHAT CAN I DO IN CLASS?

Activity #1: In simple illustrations of the limitations of the human vestibular apparatus, have a student spin around on his axis a few times, until he/she is clearly dizzy, but not overly so. Then ask the student to attempt to walk in a straight line, and observe the deviations or zig-zag - like path thy will describe. In a similar vein, have a student lie down on the floor for about 10 or 15 minutes (without going to sleep!) and ask him/her to quickly stand up and walk straight. Again there will be some zig-zag – like motion. Explain that what is happening here is that the fluid in the vestibular apparatus is being shaken to the point of becoming turbulent. This has the effect of causing rather large and sudden oscillations in the hair-like structures of the apparatus, which sends confusing electrical signals to the brain such that it compromises the ability to maintain proper balance. The effect of alcohol in the brain is somewhat similar to this.

Activity #2: In an exercise designed to improve the students' understanding of how friction works (and how it doesn't) the following simple exercise may be useful. Take a book with a known mass and place it on a table. Tie a string around it such that the string does not make contact with the table, and tie the other end of the string to a spring balance. Begin slowly dragging the book across the table, measuring the force necessary to do so by reading it off the scale. As one knows from theory, if the normal force on the book is doubled, the sliding friction should more or less double as well. So next put an identical book on top of the original one (to double the normal force), and repeat the experiment. The force required to pull the two books across the table should roughly have doubled. This illustrates two key points discussed in the chapter: the first one being that friction is directly proportional to normal force; the second one being that it is independent of contact area (in other words, no change in contact area results in a doubling of friction).

