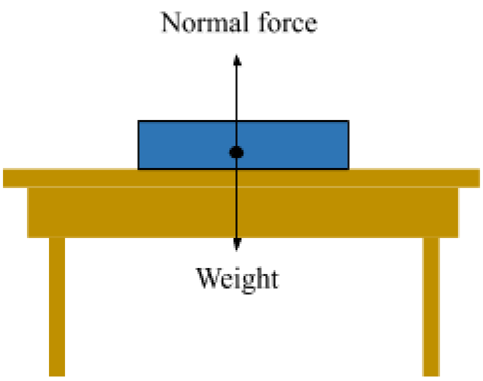
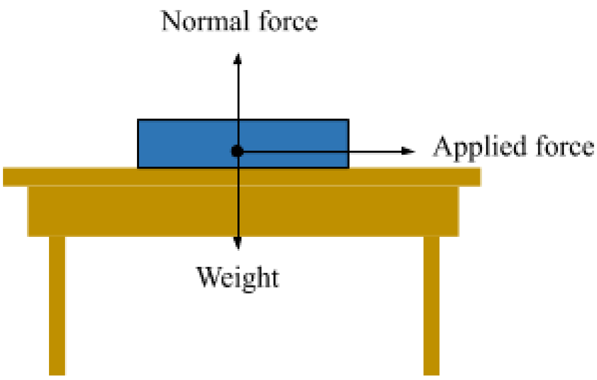
Subject Code	PHY 1	**Physics 1**
Module Code	5.0	**Newton's Laws of Motion**
Lesson Code	5.3	**Newton's 2^{nd} Law of Motion**
Time Frame		30 minutes

Components	**Tasks**	**TA[1] (min)**	**ATA[2] (min)**
Target	By the end of this learning guide, the student should be able to ● represent forces in diagrams using appropriately labeled vectors ● relate an object's acceleration to its mass and the net force acting on it ● predict how an object would accelerate knowing its mass and given one or more forces acting on it.	1	
Hook	For sure, you have encountered the following setup in your previous science classes. It involves a coin resting on top of a card. The card then rests on top of a glass. The trick is to flick the card horizontally quickly. The coin does not go with the cardboard since it tries to maintain its state of motion. However, this does not take too long. Eventually, the coin will drop inside the glass.   The setup, this time, involves the presence of unbalanced force. Situations like this can be better understood by applying Newton's second law of motion.	1	
Ignite	Let's consider a book lying on a table. There are two forces acting on the book – the book's weight and the normal force exerted by the table. If the book is at rest, the forces must be balanced. Hence we conclude that the weight and normal force are equal in magnitude.	20	

[1] Time allocation suggested by the teacher.
[2] Actual time allocation spent by the student (for information purposes only).



Suppose that someone pushes the book to the right, the forces would no longer be balanced. The unbalanced force would change the state of motion of the book. That is, the book would accelerate.



This is where Newton's second law of motion comes into the picture. It describes the effect of an unbalanced force on a body.

Newton's Second Law of Motion

If a net external force acts on a body, the body accelerates. The direction of acceleration is the same as the direction of the net force. The mass of the body times the acceleration vector of the body equals the net force vector.

(Young & Freedman, 2016)

Mathematically, we can express Newton's second law as

$$\vec{F}_{net} = m\vec{a} \qquad \text{[eqn. 1]}$$

In the SI system, force is expressed in newtons (N). A newton is equivalent to kgm/s^2. However, we shall also be familiar with the other units of force, mass, and acceleration in the CGS and Imperial measurement systems.

System	Mass	Acceleration	Force
SI	Kilogram	Meter per second squared (m/s^2)	Newton (N)
CGS	Gram	Centimeter per second squared (cm/s^2)	Dyne
Imperial	Slug	Foot per second squared (ft/s^2)	Pound (lb)

Rearranging eqn. 1, we can also write Newton's second law as

$$\vec{a} = \frac{\vec{F}_{net}}{m} \qquad \text{[eqn. 2]}$$

From Newton's second law, the acceleration of the object varies directly with the net force. This means that the greater the net force, the greater the rate of change in the velocity of the object. You can observe this when playing basketball or volleyball—greater force results in the ball's rapid movement during the game.

Moreover, the acceleration is inversely proportional to the mass. Mass is a quantitative measure of inertia. A more massive object would require a greater amount of force to change its state of motion or to accelerate. In the same manner, a more massive object would accelerate less for the same amount of force.

Newton's second law also tells us that the object will accelerate in the same direction as the net force. Net force refers to the sum of the forces acting on the body. You've learned how to determine the resultant vector from a given set of vectors. The mechanics for finding the net force on a body also follows the basic rules for adding vectors.

When solving word problems involving the second law of motion, it helps to provide a pictorial representation of the problem. We refer to this as the **free-body diagram** or **FBD.** In drawing an FBD, the object of interest is represented as a dot, and the forces acting on the object are represented as vector arrows. Each arrow must be appropriately labeled to denote the kind of forces acting on the object.

Here are some of the critical questions that we should consider in identifying forces for a free-body diagram.

Question	If it has,	What does the force look like?
1. Is the object on Earth?	Then it has weight, directed downwards.	 Weight
2. Is the object lying on a surface?	Then normal force acts on it. It is directed towards the object and perpendicular to the surface.	Normal Force 
3. For an object moving on a surface: Is friction not negligible?	Then there is friction opposite the direction of the object's motion and parallel to the surface.	 Friction *(Assuming that the direction of motion is to the right)*
4. Is there a string attached to the object?	Then there is tension directed away from the object. A string will always pull the object, it will never push the object.	Tension  *(Assuming you are referring to the tension of a cord with a chandelier suspended from the ceiling)*
5. For an object moving in air: Is air resistance not negligible?	Then there is air resistance or drag opposite to the direction of motion.	Drag  *(Assuming there is air resistance acting on a parachute as it descends from a certain altitude.)*
6. Is the object in water or other liquid?	Then there is an upward buoyant force.	Buoyant force

		 *(Assuming there is buoyant force acting on a floating object in the sea.)*
7. Is there a push or pull on the object?	Then draw an arrow to represent these applied forces.	Push or pull *(Pushed or pulled to the left)*

Let's have the following sample word problems involving Newton's second law of motion.

Example 1
A cart with a mass 15.0 kg is being pulled parallel to the ground with a force of 2.50×10^2 N. What is the cart's acceleration?

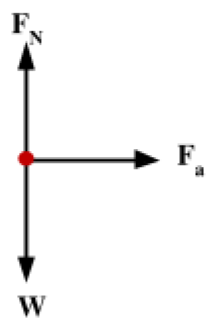
Given:

$m = 15.0$ kg
$F = 2.50 \times 10^2$ N

Required:

The acceleration of the cart (a)

To solve the problem, we need to draw first its accompanying FBD.



The motion is confined parallel to the ground and does not have a component along the vertical axis. Hence, the net force along the vertical is zero which means that the normal force (F_N) and the weight (W) cancel out. Meanwhile, the force along the direction of motion is just the applied force (F_a) that pulls the cart.

Equation:

To determine the acceleration, we will apply the equation for Newton's second law.

$$F = ma$$

Solution:
From the equation, we can derive the equation for acceleration. Plugging the given information from the word problem, we can determine the acceleration of the cart.

$$a = \frac{F}{m} = \frac{2.50\ x\ 10^2\ N}{15.0\ kg} = \frac{2.50\ x\ 10^2\ kg\ m/s^2}{15.0\ kg} = 16.7\ m/s^2$$

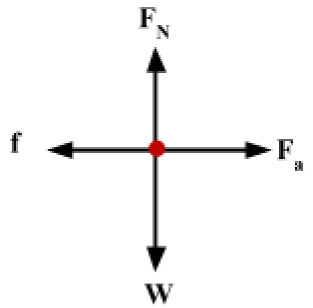
Answer:
Hence, the acceleration of the cart is **16.7 m/s²**. Following Newton's second law, this acceleration is in the same direction as the net force.

Example 2
A 5.0-kg block being pulled across a table by a horizontal force of 100.0 N also experiences a frictional force of 10.0 N. What is the block's acceleration?

Given:
m = 5.0 kg
F = 100.0 N
f = 10.0 N

Required:
Acceleration of the block (a)

Based on the problem, four forces are acting on the block. These are the weight (W), the normal force (F_N), the horizontal force of 100.0 N (F_a), and the frictional force (f). Therefore, the appropriate FBD for the block will be the following.



Equation:
The motion is confined parallel to the table and does not have a component along the vertical axis. Hence, the net force along the vertical is zero which means that the normal force (F_N) and the weight (W) cancel out. However, it was explicitly identified that the forces along the horizontal axis (the horizontal force and the

	frictional force) are not equal. Thus, this results in an unbalanced force. In effect, it will cause the block to accelerate. We need to determine the net force first before we calculate the acceleration of the block. The equation for net force applicable to this word problem shall be the following. $$F_{net} = F - f$$ To determine the magnitude of the acceleration, we can use the equation for Newton's second law of motion. $$F = ma$$ *Solution:* Applying the equation for net force, $$F_{net} = 100.0\ N - 10.0\ N = 90.0\ N$$ This means that the block is experiencing a net force of 90.0 N. After finding the net force, we can now solve the block's acceleration using Newton's second law. That is, $$a = \frac{F_{net}}{m} = \frac{90.0\ N}{5.0\ kg} = 18\ m/s^2$$ *Answer:* The magnitude of the acceleration is **18 m/s²**. According to Newton's second law its direction is along the direction of the net force, which in this case is in the same direction as the applied horizontal force.		
Navigate	Write your answers (with complete solutions and appropriate FBD) on a clean sheet of paper. Follow your teacher's instructions regarding submission. 1. A constant horizontal force of 30.0 N is exerted by a string attached to a 5.0-kg block being pulled across a tabletop. The block also experiences a frictional force of 5.0 N due to contact with the table. What is the horizontal acceleration of the block? (Griffith & Brosing, 2015) 2. A carretela pulled by a horse carries a 50.0-kg load that includes a copy of modules distributed to remote barangays. The carretela has a mass of 2.50 x 10^3 kg. If the carretela moves accelerates at a rate of 5.00 m/s^2, how much pull was exerted by the carabao?	6	
Knot	Here are some of the key takeaways after working on this learning guide.	2	

	• Newton's second law of motion describes the effect of unbalanced forces in a system. A force causes an object to accelerate. • The net force experienced by an object is directly proportional to its acceleration at constant mass. Likewise, the acceleration of a body varies inversely at constant net force. The acceleration vector is in the same direction as the net force. • Mathematically, Newton's second law can be described as $F = ma$.		

References

1. Hewitt, P. (2006). *Conceptual Physics.* Pearson Education, Inc.
2. Young, H. & Freedman, R. (2016). *Sear's and Zemansky's University Physics with Modern Physics.* Pearson Education, Inc.

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