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Problem solving of Newton's second law through a system of total mass motion

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Abstract

Nowadays, many researchers discovered various effective strategies in teaching physics, from traditional to modern strategy. However, research on physics problem solving is still inadequate. Physics problem is an integral part of physics learning and requires strategy to solve it. Besides that, problem solving is the best way to convey principle, theory, law, and formulation to students. This paper describes a new strategy in solving physics problems especially problems related to the application of Newton's second law. This strategy use a principle named system of total mass motion (STMM).

Keywords: problem solving, Newton's second law, system of total mass motion

Introduction

Problem solving is an important element as well as an integral part of physics. The core of physics matter is logic. Principle and theory in physics describe in logical mathematics in the form of formulation. As an example, Newton second law is expressed as follows:

$$a=(\sum F)/m \quad (1)$$

This equation describes the relationship between acceleration (a) with force (F), while mass (m) is the object in which both quantities are applied. Force is a cause factor and acceleration is the effect, so that an object will be accelerated when a force act upon it. This indicates that equation (1) describes logical thinking about the movement of an object. Based on this view, physics problem is built on the basis of logical thinking. As a consequence, problem solving requires a certain procedure.

In teaching physics, problem solving is an important part of teaching strategy (Ibrahim and Rebello, 2013). This is because problem solving helps students to comprehend concepts, principles, laws and formulations. Problem solving is a tool to train thinking process. Therefore, many researchers recommend problem solving strategy to be applied in teaching physics (Hull, Kuo, Gupta, and Elby, 2013).

A number of physics university text books such as Serwey & Jewett (2004), Kerr & Ruth (2008), Bauer & Westfall (2011) describe problem solving procedures. The most popular one is by using "Free body diagrams (FBD)". FBD is used particularly to solve problems related to Newton's second law. The strategy used is to use free diagram (Savinainem, Mäkynem, Nieminem, and Viiri, 2013) As an example a movement of an object on the surface of a table and pull by another object (Figure 1 and 2),

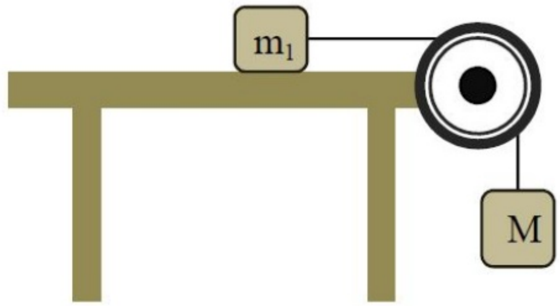

Figure 1.

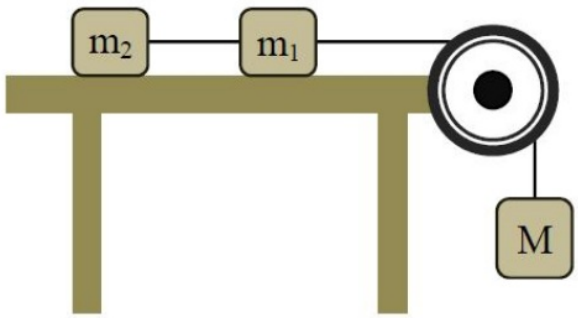

Figure 2.

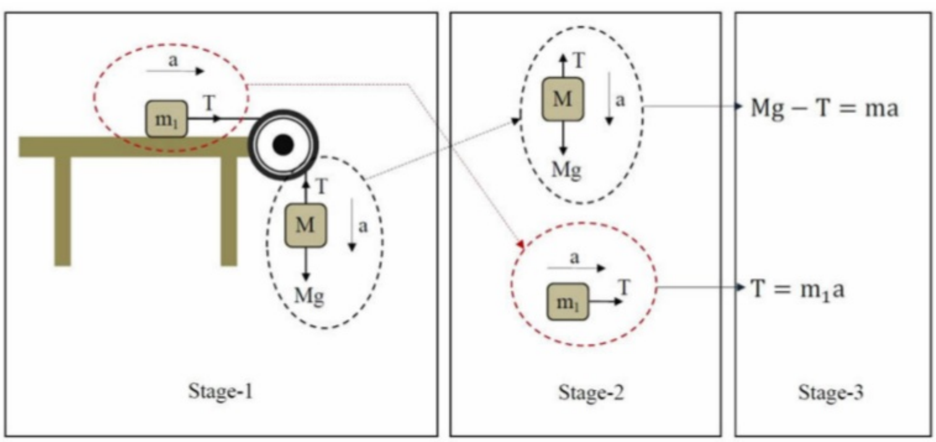

Figure 3. FBD problem for Fig-1

If the mass of the string and the pulley as well as the friction is neglected, the acceleration of the system can be determined by using the following procedure: (1) drawing force components (2) separating motion system for each object or creating, (3) using Newton's second law to formulate each object, and (4) executing by using mathematical operation. For a problem in Fig-1, the solution stages is pictured in Fig-3.

Stage 4 is executing equations in Fig-3 by substituting both expressions to find the acceleration. The result is,

$$a=Mg/(M+m_1)$$

For a problem in Fig-2, the solution procedure is similar to problem in Fig-1, except that there is m2 behind m1. The solution of stage 1 is shown in Fig-4. The result of this stage is:

$$a=Mg/(M+m_1+m_2)$$

From both problems, it appears that if the system consists of two objects, the number of equation is 2, and 3 equations for 3 objects. Hence, if the system consists of n objects, the number of equation is also n. If this strategy is used, the main difficulties are the number of equation increase with the number of object. In order to overcome this problem, we propose a strategy to solve Newton's law by using "System of Total Mass".

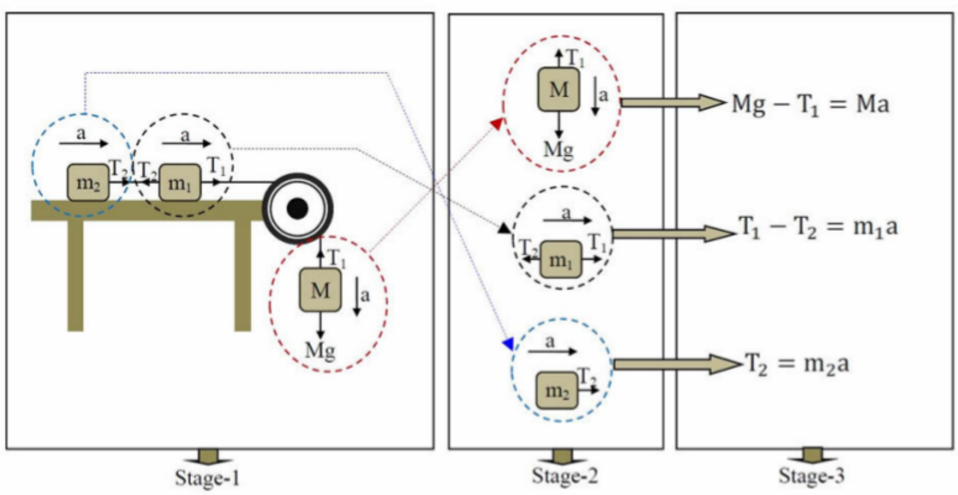

Figure 4. FBD for problem fig-2

Definition

System of total mass motion is a strategy to solve Newton's second law by considering the motion of object as a system. The procedure follows equation (1), in the form of,

$$a=(\sum F)/m_s=(\sum \text{motion force}-\sum \text{resistive force})/m_s \quad (2)$$

In this system, ∑F is divided into two components namely motion force and resistive force. Motion force is the sum of all forces to move the system, resistive force is the sum of all forces to slow the movement of the system. Fig-5 is an example for this case.

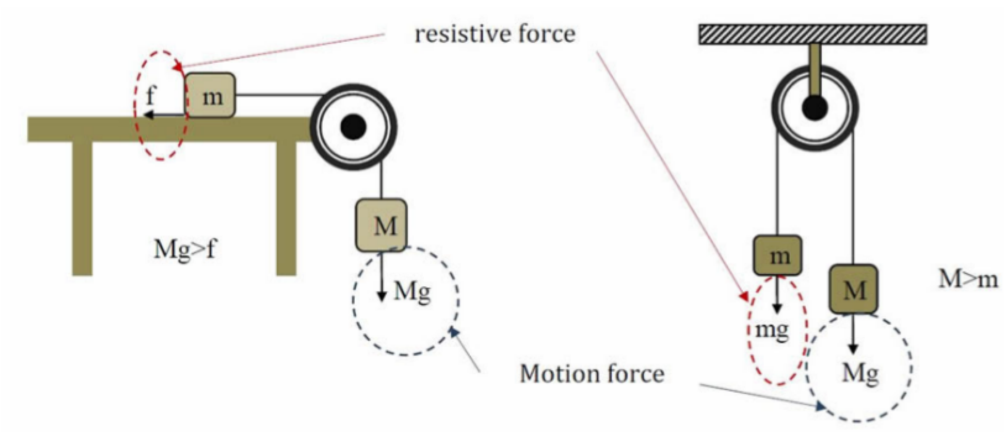

Figure 5. An example of motion and resistive force

Because Mg>f or M>m and the mass of pulley and string are neglected, M will move downward. The component force for the object and pulley is Mg and the component for resistive is f. For the hanging pulley, the component force is Mg and its resistive force is mg. Hence, the acceleration of the object for both systems is as follows. For the object:

$$a=(\sum F_{motion}-\sum F_{resistive})/m_s=(Mg-f)/(M+m)$$

For the pulley system:

$$a=(\sum F_{motion}-\sum F_{resistive})/m_s=(Mg-mg)/(M+m)=(M-m)g/(M+m)$$

Solution strategy for "system of total mass movement" consist only two stage procedures, namely: (1) drawing force components or drawing FBD and (2) applying the formula. The other advantage of this strategy is does not require rigorous formulation. The formulation (2) can be used directly. Besides that, this strategy is able to solve a problem contain many objects (Fig-6).

Substituting the above equations, the acceleration of a series of objects can be written as,

$$a=(F-(f_1+f_2+f_3+f_4+f_5))/(m_1+m_2+m_3+m_4+m_5) \quad (3)$$

If the principle of system of total mass is used, the next stage after drawing FBD is finding the force components to determine the motion and the resistive force:

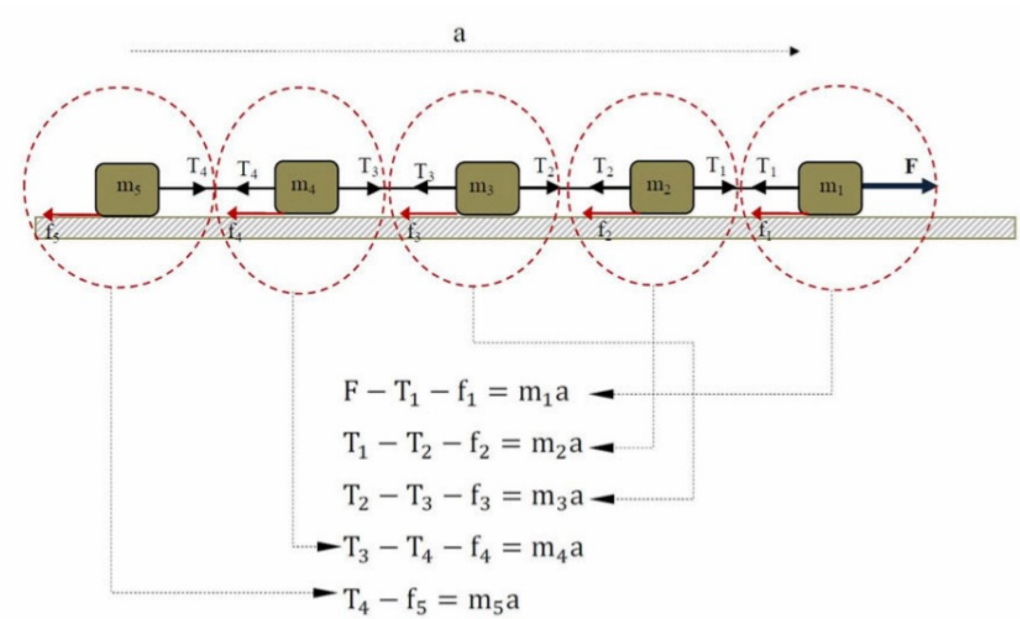

Figure 6. System of a series of objects

$$\sum F_{motion}=F$$

$$\sum F_{resistive}= f_1+f_2+f_3+f_4+f_5$$

and

$$m_s=m_1+m_2+m_3+m_4+m_5$$

The acceleration of the system,

$$a=(\sum F_{motion}-\sum F_{resistive})/m_s=(F-(f_1+f_2+f_3+f_4+f_5))/(m_1+m_2+m_3+m_4+m_5) \quad (4)$$

This equation is similar with equation (3).

Application

Strategy of total mass can also be applied to various problems where the mass of pulley is not neglected. The mass of the pulley (m) is written as m_i. This term is used to find the total mass. As an example, the moment of inertia of the pulley is given by $I=1/2\ mR^2$, in general can be written as:

$$I=1/2\ mR^2=cmR^2=m_iR^2$$

Here for the pulley mass the value of c =1/2 (constant), and m_i = 1/2 m=cm. By this definition the total mass motion can be determined easily. In order to know the application of the total mass strategy, the problem in a plane, a hanging pulley and an elevated plane will be considered.

(a) Problem on a plane and a hanging pulley

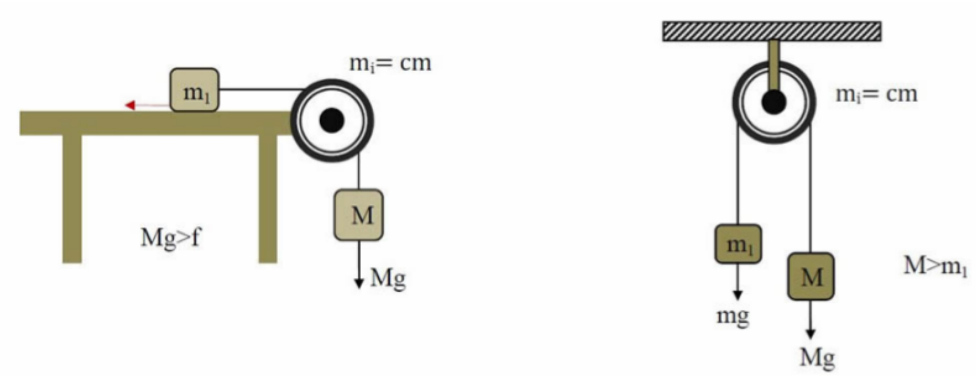

Figure 7. System of an object and a pulley

The mass of string is neglected, but the mass of the pulley is included. By using the strategy of total mass motion, the system of the object on the table can be determined as follows,

$$\sum F_{motion}=Mg$$

$$\sum F_{resistive}= f$$

and

$$m_s=M+m_1+m_i=M+m_1+cm$$

Hence, the acceleration of the system of the object is given by,

$$a=(Mg-f)/(M+m_1+cm)$$

for the object and the pulley, we have:

$$\sum F_{motion} =Mg$$

$$\sum F_{resistive}= mg$$

and

$$m_s=M+m_1+m_i=M+m_1+cm$$

We get:

$$a=(Mg-mg)/(M+m_1+cm)$$

(b) Problem on elevated plane

An object with a mass of m1 rested on an elevated beam connected by a string to a pulley with a radius of R ($I = 1/2\ mR^2$) and the other end is connected to a load with a mass of M. If M is moving downward, its acceleration can be determined as follows,

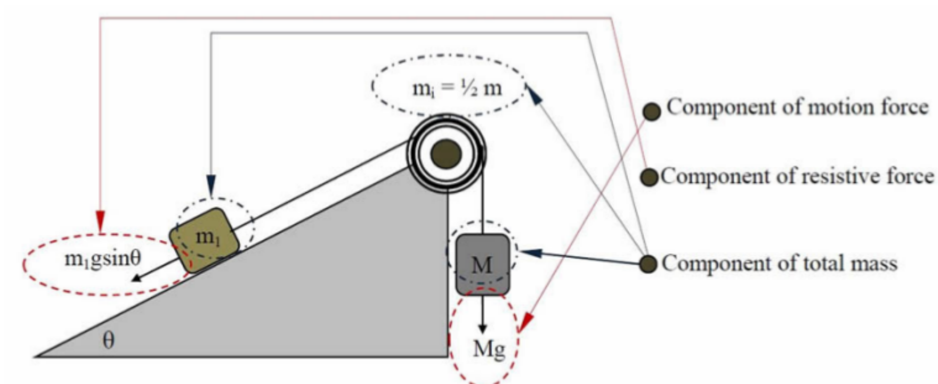

Figure 8. FBD of an elevated plane

Based on Fig-8, the acceleration of M can be find easily as follows.

$$a=(Mg-m_1\ g\sin\theta)/(M+m_1+1/2\ m)=((M-m_1\ \sin\theta)g)/(M+m_1+1/2\ m)$$

Implication in physics teaching

The use of strategy of total mass motion is one way to comprehend the application of Newton's second law in various motion systems. This strategy is appropriate to be used in fundamental physics lecture for year one university student. This is because the students have already basic knowledge about Newton's second law from high school, so that at the university level the application of the law can be given directly. By given more exercise of physics problems student will strengthen their understanding of the subject, and the solution using strategy of total mass motion is an effective way in improve students comprehension on the application of principles, laws, and formulation comprehensively.

However STMM has limited its use. STMM only be used for cases of force and motion straight, while for cases such as momentum, equilibrium systems, rolling motion, vibration, and other topics are very difficult to implement.

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