Adapting the S.I.M. (System, Interactions, and Model) physics problem solving strategy to Engineering Statics and an application to frictional forces on screws

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***Abstract* – Many students struggle with Engineering Statics, a core lower-division Engineering class. Current education research suggests using overarching themes to tie concepts together and to generate deeper understanding. Recent physics education research has found success using the S.I.M. (System, Interactions, and Model) problem solving strategy. Since first-semester physics (classical mechanics) is a prerequisite for Engineering Statics, adapting the S.I.M. strategy to Engineering Statics will leverage prior knowledge and improve student learning. This article suggests an adaptation, referred to as the problem-solving flowchart, which can be used to analyze almost all core Engineering Statics topics, such as equilibrium of a particle, equilibrium of a rigid body, structural analysis, internal forces and friction. One challenging topic in Engineering Statics is analyzing the impending motion of a square-threaded screw with friction between the thread and the mating groove. The broadly accepted analysis runs contrary to the spirit of the S.I.M. strategy. It also uses a free body diagram that is counter-intuitive to students. This article applies the suggested problem-solving flowchart, and proposes a free body diagram. The result is a more intuitive analysis, which will improve student learning.**

Index Terms – Engineering Statics, Education Research, Problem Solving Strategy, Frictional Forces on Screws

INTRODUCTION

To motivate the discussion of problem solving in mechanics, we offer a quote from MIT Physics Professor David Pritchard's Education Research Group:

"Standard mechanics teaching materials emphasize declarative and procedural knowledge, but not the strategic knowledge which is essential to the application of these facts and procedures in problem solving. (Pawl, 2009)"

The S.I.M. (System, Interactions, and Model) [1] physics problem solving strategy, created by this MIT education research group, provides an overarching theme to tie physics concepts together and to generate deeper understanding.

ADAPTING THE S.I.M. PHYSICS PROBLEM SOLVING STRATEGY TO ENGINEERING STATICS

In Engineering Statics, we encounter three types of systems: a particle, a rigid body, and a system of multiple objects. We first identify the objects or partial objects which should be included in the system. Once the system is identified, we analyze the interactions between the system and the external environment to determine all the forces acting on the system and then draw the free body diagram (FBD) of the system. Examples and their corresponding FBDs are listed in the table on the next page. Each identified system is enclosed in a purple dashed line.

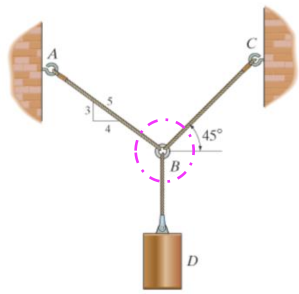
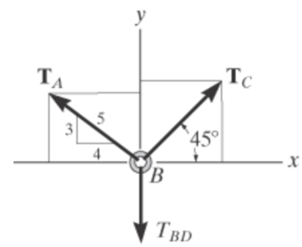
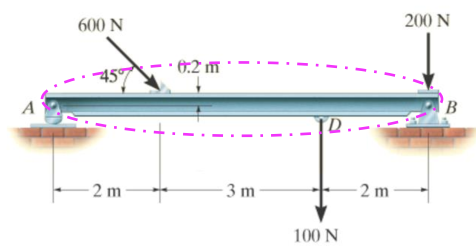
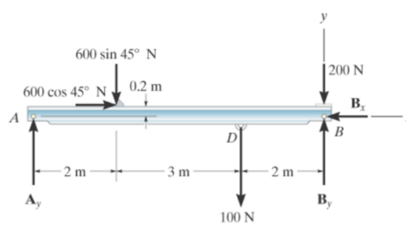
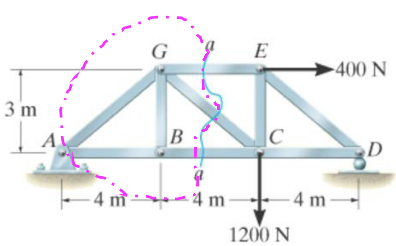
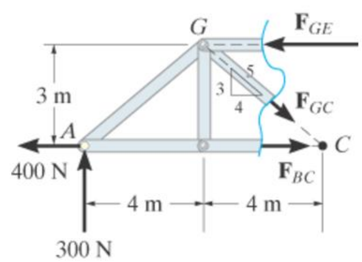
In Engineering Statics, we only encounter one model, the static equilibrium model, which includes the impending motion model. With this model, we build equations. If we are dealing with a 2D problem, we target building three scalar equations of equilibrium. If we are dealing with a 3D problem, we target building six scalar equations of equilibrium. If we are dealing with friction, then we may need to add more impending motion (slipping or tipping) equations. In Engineering Statics, the problems are generally solvable so the number of unknowns will be equal to or less than the number of independent equations we can build. Once we have the equations, with the help of technology, we will find the answers.

In summary, by adapting the S.I.M. physics problem solving strategy to Engineering Statics, the overarching theme that ties concepts together and generates deeper understanding becomes elegantly simple:

System → FBD → Equations → Answers

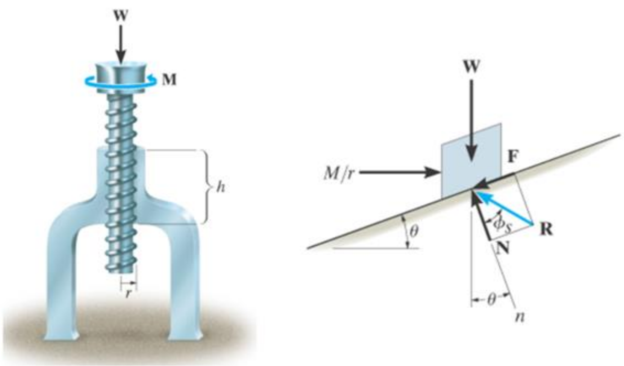
From now on, we will refer to this as the problem-solving flowchart. We use one flowchart per system. To solve multiple-system problems with multiple flowcharts, simply determine the order in which to solve each system.

Table of Examples in Engineering Statics for Three Different Types of Systems and Their FBDs

Systems	Examples	FBDs
A Particle [2]		
A Rigid Body [3]		
Multiple Objects [4]		

APPLYING THE PROBLEM-SOLVING FLOWCHART TO FRICTIONAL FORCES ON SCREWS

When it comes to the impending motion of a square-threaded screw with friction between the thread and the mating groove, the broadly accepted FBD is a block with an impending motion along an incline [5][6]. In this article, we only look at the case of determining the moment needed to move the screw against a given axial load when the motion is pending. The classical FBD is shown below:



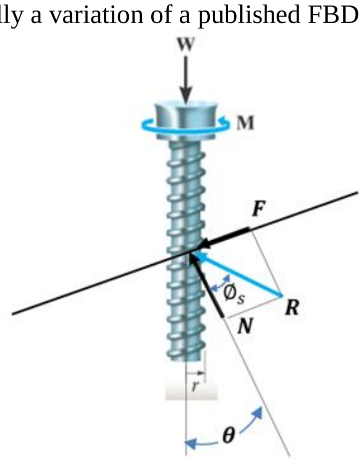
$$M = rW\tan(\theta + \phi_s)$$

Although the ensuing equations (static equilibrium model for the point-mass block) and the derived answer are correct, the above FBD is counter-intuitive. Students may have difficulty visualizing a screw and its base as a block on an incline. This added layer of complexity negatively affects the problem-solving process. In addition, since now we are looking at a block, not the screw, it is against the S.I.M. strategy. The spirit of the S.I.M. strategy is to identify the system first. Then we analyze the interactions between the system and the environment in order to determine all the forces acting on the system for the purpose of drawing the FBD of the system.

Now let's apply the problem-solving flowchart to this topic:

System → FBD → Equations → Answers

Since we are concerned with the impending motion of the screw, the screw itself should be the system. Since rotational motion tendency is involved, this is a rigid body type of system. Now we are ready to analyze the interactions between the system and the external environment in order to draw the FBD of the system. This article proposes the FBD shown below, originally inspired from a YouTube video [7] and essentially a variation of a published FBD [8]:



It is easy to see that W and M are due to the interactions between the screw and the external environment. R is due to the interaction between the thread of the screw and the mating groove of the external environment. This interaction is supposed to be a continuous or distributed force. However, in terms of the external effect on the screw, the discrete or concentrated force is equivalent to the continuous or distributed force. Due to the impending motion condition, R and the normal line from the contact surface construct the angle of static friction, $\emptyset s$.

To build equations, we use the static equilibrium model. Since the screw has a tendency to translate in the axial direction and rotate about the axial line, we will build two equations:

1. Net force in the axial direction is zero:
   $W=R\cos(\theta+\emptyset s)$
2. Net moment about the axial line is zero:
   $M=R\sin(\theta+\emptyset s)r$

We have built two equations. Although there are two unknowns (M and R), we are only interested in M. Dividing the second equation by the first equation, we obtain:

$$M=rW\tan(\theta+\emptyset s)$$

We now have derived the same result as above. However, applying the problem-solving flowchart provides a more intuitive analysis and helps to choose a better FBD.

CONCLUSION

This article provides a problem-solving flowchart for Engineering Statics by adapting the S.I.M. physics problem solving strategy. It can be used to analyze almost all core Engineering Statics topics, such as equilibrium of a particle, equilibrium of a rigid body, structural analysis, internal forces and friction. Applying this problem-solving flowchart to the challenging topic of the impending motion of a frictional square-threaded screw creates a more intuitive process and leads to choosing a better FBD, which will improve student learning.

REFERENCES

[1] Pawl A., Barrantes A, and Pritchard, D., E., "Modeling Applied to Problem Solving", *AIP Conf. Proc.*, 1179, 2009, 51–54.

[2] Hibbeler, R. C., "Engineering Mechanics Statics", 14th edition, 2016, 93.

[3] Hibbeler, R. C., "Engineering Mechanics Statics", 14th edition, 2016, 222.

[4] Hibbeler, R. C., "Engineering Mechanics Statics", 14th edition, 2016, 294.

[5] Hibbeler, R. C., "Engineering Mechanics Statics", 14th edition, 2016, 433.

[6] Beer, F., P., Johnson, E., R. and Mazurek, D. F., "Vector Mechanics for Engineers: Statics", 11th edition, 451.

[7] https://www.youtube.com/watch?v=msZFxGyLP5c (dead link as of April 2017)

[8] Bedford, A. and Fowler, W., "Engineering Mechanics: Statics", 5th edition, 2008, 452.