Work In Progress: The Effects of Embedded-Formatting Applied to Statics

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Introduction

A method often utilized for conveying novel information to students regarding problem solving within engineering textbooks is the use of worked examples, otherwise known as example problems. Worked examples have been shown to be very effective in order to reduce cognitive load, however there are many instances where worked examples may be ineffective.[2] One instance is where a worked example may contain a number of unique pieces of information, each being incomprehensible to the learner in isolation, therefore the learner must mentally integrate each piece in order to understand the instructional material. A classic example of this is having a picture of a graph consisting of lines and then separately below having a list of equations for each line. There is a need for the learner to mentally integrate the two different sources of information, which asserts an increased burden on cognitive load therefore stifling the learning process. This is what is referred to as the split-attention effect.[7]

Literature Review

Cognitive Load Theory (CLT) should be considered when designing instruction in order to maximize student learning. Specifically, three types of cognitive load have been identified in affecting a student's working memory capacity (i.e. intrinsic, extraneous, and germane). Intrinsic cognitive load deals with the nature of the material being learned, extraneous cognitive load is affected by the manner in which the material is delivered to students, while germane cognitive load involves the effort involved to create a schema.[3,7] Instructional design is important for both limiting extraneous load in order to maximize germane cognitive load (i.e. support for learning).[3] Unfortunately, the organization of content within many Statics textbooks places a burden on extraneous and germane cognitive load due to the use of standard designed worked-examples, which can likely lead to split-attention effect.

One way that has been shown to alleviate this problem is the use of embedded-formatting.[5] Embedded formatting is where the unique portions of information are physically integrated with one another in order to reduce cognitive load. So, for example the graph with line equations described earlier could be shown where the equations are displayed on the graph directly next to the line that it is defining, so that the reader does not have to integrate the two mentally - it can be done visually.

Purpose Statement

Statics is typically one of the first core-engineering courses many types of engineering students take, therefore much of the information in this class is novel to the learner. Worked examples are often used in textbooks and are very useful, but they generally consist of a free-body diagram (FBD) and then a separate list of accompanying equilibrium equations for that specific FBD. This requires the learner to mentally integrate the two novel sources of information in order to make sense of the worked example, which can cause cognitive overload or an overload on working memory. This study will focus on identifying the effectiveness of using embedded-formatting with regards to engineering Statics worked examples. This study will specifically examine whether or not the use of embedded formatting creates a more efficient and complete learning process when learning Statics, specifically problems dealing with friction.

Design/Methods
For this study a quantitative quasi-experimental pretest-posttest study will be utilized to gain a better understanding of the effects of applying embedded-formatting to worked examples of Statics problems on student learning. Students within one engineering Statics course will be considered and divided into two groups. Where the first group will be given worked examples utilizing embedded-formatting and the second group will be given traditional worked examples as part of their instructional material. Additionally, a subjective measure of cognitive load will be used to quantify between group cognitive loads, while a posttest will measure student learning of the topic in general. The instructional technique will serve as the independent variable consisting of two groups; while the engineering concept knowledge of Statics, along with the subjective cognitive load scores will serve as the dependent variables to be measured using multivariate analysis of variance (MANOVA).

Pre-test
Students will first complete a pre-test to identify their baseline Statics knowledge regarding basic friction problems. Figure 1 shows an example of a sample pre-test question where students will be asked to solve for unknown external forces acting on an object involving friction.
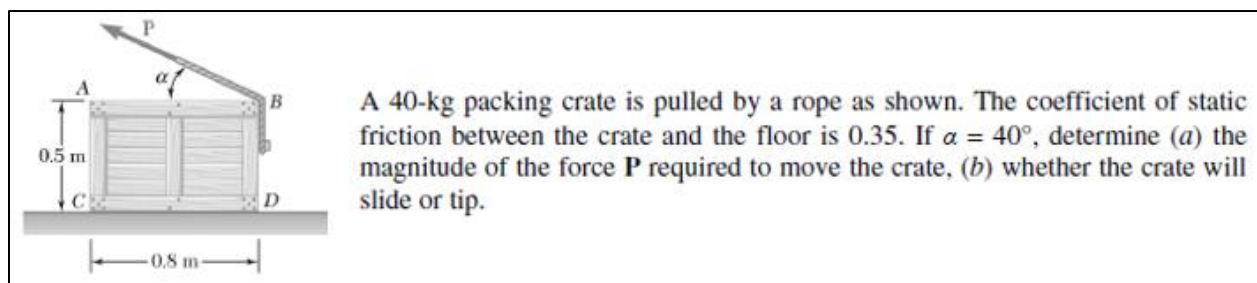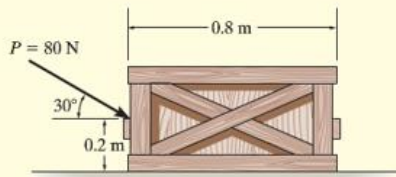

A 40-kg packing crate is pulled by a rope as shown. The coefficient of static friction between the crate and the floor is 0.35. If $\alpha = 40°$, determine (a) the magnitude of the force P required to move the crate, (b) whether the crate will slide or tip.

Figure 1. Pre-test sample question.[1] Reprinted from Vector Mechanics for Engineers: Statics & Dynamics, (p.442), F., Beer et al, 2016, McGraw-Hill Education.

Group 1: Embedded-Formatting Examples
Following traditional instruction students in this group will be given a worked example that is setup using embedded-formatting, which will be used as reference material to solve a similar in-class problem. At the end of class students will be given a homework assignment, where they will be provided another worked example utilizing embedded-formatting that is to be used as a reference to complete the homework assignment. Students will then turn in their completed homework assignment and take a three question post-test upon arrival of their next class. Figure 2 shows an illustration of a worked example utilizing embedded-formatting.

The uniform crate shown in Fig. 8–7a has a mass of 20 kg. If a force $P = 80$ N is applied to the crate, determine if it remains in equilibrium. The coefficient of static friction is $\mu_s = 0.3$.

0.8 m

$P = 80$ N

30°

0.2 m

SOLUTION:

FBD

20 kg x 9.81 m/s² $\quad + \uparrow \Sigma F_y = 0;$

196.2 N

$\xrightarrow{+} \Sigma F_x = 0;$

$P = 80$ N $\quad$ 0.4 m $\quad$ 0.4 m

3 unknowns: F, Nc, x

30°

0.2 m

O

$\xrightarrow{+} \Sigma F_x = 0; \qquad 2$
$80 \cos 30° \text{ N} - F = 0$
$F = 69.3 \text{ N}$

F

$\leftarrow x \rightarrow$

$F_{max} = \mu_s N_c = 0.3(236.2 \text{ N}) = 70.9 \text{ N}.$
Since F = 69.3 N, the crate will not slip, but it is getting close to slipping.

N_C

Distance from crate's center line to counteract tipping effect from P

$+\uparrow \Sigma F_y = 0; \qquad 1$
$-80 \sin 30° \text{ N} + N_C - 196.2 \text{ N} = 0$
$N_C = 236.2 \text{ N}$

$\zeta + \Sigma M_O = 0; \qquad 3$
$80 \sin 30° \text{ N}(0.4 \text{ m}) - 80 \cos 30° \text{ N}(0.2 \text{ m}) + N_C(x) = 0$
$x = -0.00908 \text{ m} = -9.08 \text{ mm}$

x is negative, which means the normal force, N_c, acts to the left of the centerline of the crate.

Figure 2. Embedded-formatting worked example sample.[3] Reprinted from Engineering Mechanics: Statics, (p.397), R., Hibbeler, 2013, Pearson Prentice Hall.

Group 2: Traditional Examples

Following traditional instruction students in this group will be given what would be considered a traditional worked example, which will be used as reference material to solve a similar in-class problem. At the end of class students will be given a homework assignment, where they will be provided another worked example in traditional format that is to be used as a reference to complete the homework assignment. Figure 2 shows an illustration of a traditional worked example. Students will then turn in their completed homework assignment and take a three question post-test upon arrival of their next class.

The uniform crate shown in Fig. 8–7a has a mass of 20 kg. If a force $P = 80$ N is applied to the crate, determine if it remains in equilibrium. The coefficient of static friction is $\mu_s = 0.3$.
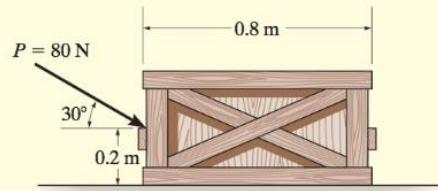
(a)

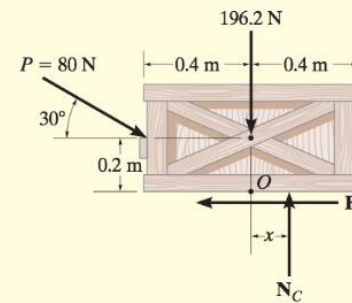Fig. 8–7

SOLUTION

Free-Body Diagram. As shown in Fig. 8–7b, the *resultant* normal force N_C must act a distance x from the crate's center line in order to counteract the tipping effect caused by **P**. There are *three unknowns*, F, N_C, and x, which can be determined strictly from the *three* equations of equilibrium.

Equations of Equilibrium.

$$\xrightarrow{+} \Sigma F_x = 0; \qquad 80 \cos 30° \text{ N} - F = 0$$

$$+\uparrow \Sigma F_y = 0; \qquad -80 \sin 30° \text{ N} + N_C - 196.2 \text{ N} = 0$$

$$\zeta + \Sigma M_O = 0; \quad 80 \sin 30° \text{ N}(0.4 \text{ m}) - 80 \cos 30° \text{ N}(0.2 \text{ m}) + N_C(x) = 0$$

Solving,

$$F = 69.3 \text{ N}$$
$$N_C = 236.2 \text{ N}$$
$$x = -0.00908 \text{ m} = -9.08 \text{ mm}$$

(b)

Figure 3. Traditional worked example sample.[3] Reprinted from Engineering Mechanics: Statics, (p.397), R., Hibbeler, 2013, Pearson Prentice Hall.

Post-test: Statics Concepts Involving Friction

During the next class (i.e. following the instructional period), both groups will be given the same instructions to complete a series of post-test tasks. During each task, students will also record how difficult they perceive the task to be (i.e. cognitive load assessment). Figure 4 depicts an example of a post-test task.
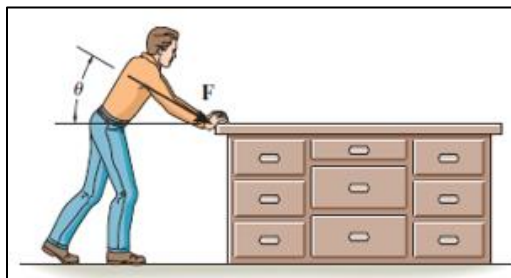
The uniform dresser has a weight of 90 lb and rests on a tile floor for which $\mu_s = 0.25$. If the man pushes on it in the horizontal direction $\theta = 0°$, determine the smallest magnitude of force F needed to move the dresser. Also, if the man has a weight of 150 lb, determine the smallest coefficient of static friction between his shoes and the floor so that he does not slip.

Post-Test: Measuring Cognitive Load

Subjective measures of cognitive load will also be used to measure students' perceived difficulty when performing the post-test tasks. Students will rate their perceived mental effort based on a 7-point Likert scale, ranging from 1 – extremely east to 7 – extremely difficult, after interpreting the instructions for each task. This approach has been used in prior research and has been shown to accurately gauge the amount of mental effort exerted by participants.[6,7]

Implications

Strong student understanding of fundamental courses such as Statics is crucial for their success in subsequent courses, and is also vital in providing solid background knowledge to appropriately comprehend more advanced topics. In order to maximize the learning process a clearer understanding of how the role of the split-attention effect during engineering based problem solving impacts student learning is necessary. This study hopes to shed light on the way in which the physical layout of both illustrative and mathematical information together impacts learning of engineering concepts.

References

1. Beer, F. et al, (2016). Vector Mechanics for Engineers: Statics & Dynamics (11th ed.) New York, NY: McGraw-Hill Education.

2. Carrol, W. (1994). Using worked examples as an instructional support in the algebra classroom, *Journal of Educational Psychology, 86*: 360-367.

3. Cierniak, G., Scheiter, K., Gerjets, P. (2009). Explaining the split-attention effect: Is the reduction of extraneous cognitive load accompanied by an increase in germane cognitive load?, Computers in Human Behavior, 25: 315-324.

4. Hibbeler, R., (2016). Engineering Mechanics: Statics (13th ed.) Upper Saddle River, NJ: Pearson Prentice Hall.

5. Mayer, R., & Gallini, J. (1990). When is an illustration worth ten thousand words?, *Journal of Educational Psychology*, *82*, 715–726.

6. Paas, F. G., Van Merriënboer, J. J., & Adam, J. J. (1994). Measurement of cognitive load in instructional research. Perceptual and Motor Skills, 79(1), 419-430.

7. Sweller, J., van Merrienboer, J. & Paas, F. (1998). Cognitive Architecture and Instructional Design, *Educational Psychology Review, 10*: 251-296.