

Staged Solutions as a Means of Learning via the Internet

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Abstract

In engineering fundamentals courses such as Statics, Dynamics, and Fluid Mechanics, learning the process of analysis is as important as the answers. But, when learning over the Internet, teachers are restricted to simple interactions such as multiple choices, select an object, drop and drag, and key word answers. So, how does one teach the process of analysis with these very simple interactions? This paper presents a technique the author calls “Staged Solutions” that attempts to address the learning of higher-level analysis skills. Basically, the concept is to lead the learner through a series of low-level interaction questions that contain all the elements of the analytical process. An example of this approach to teaching problem-solving skills over the Internet as applied to Statics is presented in this paper.

1. Introduction

The primary goal of engineering fundamentals courses, such as Statics, Dynamics, and Thermodynamics, is to develop the analytical skills required to apply concepts learned in courses such as Physics and Mathematics to engineering situations. Secondary goals are to develop mastery of basic concepts, to demonstrate the utility of science and mathematics, and to begin the transformation from student to engineer. Often, these courses are taught in large sections with limited mentoring and feedback. Current pressures to increase teaching efficiency are compounding this situation.

A common means of learning and mastering analytical skills is to have the students learn and use a process that can be applied to large classes of situations. These processes are somewhat course specific and are widely utilized. In Statics, students learn to:

1. Clearly understand the problem
2. Proceed to develop a graphic representation of the problem
3. Apply the force and moment equilibrium principles to the graphical representation
4. Solve the equilibrium equations for the unknown quantities
5. Review the results for reasonableness.

Other courses use similar processes for the purpose of student mastery of analytical skills. While executing the process, students learn or reinforce other skills such as solving algebraic equations, performing integrations, applying engineering definitions, and assigning sign conventions, for example. But, the goal is the mastery of the process.

In view of current efficiency pressures, student expectations, and modern student constraints, computer-based-instruction (CBI) administered through the Internet is becoming more prevalent in engineering fundamentals course. The question then becomes one of how we assist students with mastering the analytical process within the interaction limitations of CBI.

It is well known that students learn more as they become more engaged with the materials. Reiseman and Carr [5] have concluded that students learn 20% of the material taught by hearing, 40% by seeing and hearing, and 75% by seeing, hearing, and doing. Highly interactive, well-designed CBI modules offer the possibility of achieving the 75% goal. Renshaw, et al. [6] state “students unanimously preferred modules that incorporated animations and interactive design tools.” Others [1-4,7] have reported similar findings in several engineering fields and topics. Since students prefer interactive multimedia modules and retain more material presented in this way, the goal of any CBI module should be to use interactive engaging material rather than static material.

“Staged solutions” are one approach to achieving the goal of mastering the process while simultaneously incorporating highly interactive CBI. A staged solution is a CBI technique where the student proceeds through the solution of a problem in a step-by-step manner. Each step of the staged solution uses the limited interactions available in most CBI software; button clicking, multiple/true-false choice, drop and drag, short answers, graphic hot spots, and matching lists; in a manner consistent with objectives of each step of the solution process. For example, students may select the free-body-diagram from several multiple choices or build one by dragging force vectors onto a blank diagram. Coaching/mentoring is accomplished at each step by constructive comments made each time the student interacts with the CBI material, either correctly or incorrectly.

This paper describes an application of staged solutions to a typical Statics course. The analytical steps to be mastered by students are:

1. Problem familiarization and understanding
2. Development of the free-body-diagram
3. Writing the equilibrium equations
4. Solving the equilibrium equations
5. Problem review and answer reasonableness

These steps are typical of most Statics courses. The specific application selected for this paper is the impending motion of two bodies with a force applied to one and friction forces acting on both.

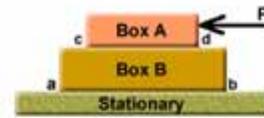
2. Problem Familiarization

A screen shot of the first screen which states the problem is presented in Figure 1. Students are to determine the magnitude of force P required to initiate motion of box A, the upper box.

Figure 1 is also the beginning of the Problem Familiarization step. The statement in the lower left block explains to the student that motion can begin in two different ways. Students are to select the correct two ways from the list in the lower right-hand block. Observe that several ways in which block A can move are included in the list so that students can exercise and develop their discrimination skills.

Problem Statement

Box A in this system has a weight of W_A while box B has weight W_B . At interface cd, the coefficient of friction is μ_{cd} and at interface ab, it is μ_{ab} . Determine the magnitude of the force P that will cause box A to move in a horizontal direction to the left when: $W_A = 10 \text{ N}$, $W_B = 5 \text{ N}$, $\mu_{cd} = 0.4$, and $\mu_{ab} = 0.2$.



Understand the Problem

Any motion of box A in the horizontal direction occurs when the resultant force acting on the system is non-zero and acts to the left (i.e. impending motion). Since friction forces act on both surfaces ab and cd, motion of box A can occur in two ways. Select the two ways by clicking on the proper selections in the list to the right.

Box A and box B tip over about point A

Box A and box B slide together along surface ab

Box A tips over about point c

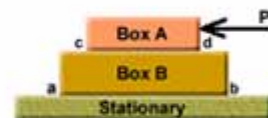
Box A slides along surface cd while box B remains stationary

Fig.1 Problem Statement

A shot of the screen when an incorrect choice is made is shown in Figure 2. A constructive comment is added to the lower left-hand block to explain to the student why the choice they have made is incorrect. In this way, students learn about other box A motion modes and the conditions under which these modes need not be considered. Again, the goal of constructive comments and instantaneous feedback

Problem Statement

Box A in this system has a weight of W_A while box B has weight W_B . At interface cd, the coefficient of friction is μ_{cd} and at interface ab, it is μ_{ab} . Determine the magnitude of the force P that will cause box A to move in a horizontal direction to the left when: $W_A = 10 \text{ N}$, $W_B = 5 \text{ N}$, $\mu_{cd} = 0.4$, and $\mu_{ab} = 0.2$.



Understand the Problem

Any motion of box A in the horizontal direction occurs when the resultant force acting on the system is non-zero and acts to the left (i.e. impending motion). Since friction forces act on both surfaces ab and cd, motion of box A can occur in two ways. Select the two ways by clicking on the proper selections in the list to the right.

NO! We are presuming that the two boxes are wide enough that they won't tip over and will only consider horizontal motion. Click on another selection.

Box A and box B tip over about point A

Box A and box B slide together along surface ab

Box A tips over about point c

Box A slides along surface cd while box B remains stationary

Fig. 2 Constructive Comments

accomplish learning regardless of the choices made by the students.

Once the student has correctly identified the two modes by which box A can move, they proceed to complete the problem familiarization step by identifying the governing mode. The screen that is

used to accomplish this is shown in Figure 3. Again they are presented with a multiple-choice question that includes constructive feedback for the correct and incorrect answers.

At both stages of identifying the problem, students are not allowed to proceed until they have correctly answered the questions. Thus, students are not allowed to proceed until they completely understand each step of the problem they are to solve.

3. Free-Body-Diagram Development

The freehand drawing of a free-body-diagram (FBD) in a

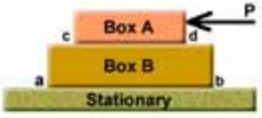
Problem Statement

Box A in this system has a weight of W_A while box B has weight W_B . At interface cd, the coefficient of friction is μ_{cd} and at interface ab, it is μ_{ab} . Determine the magnitude of the force P that will cause box A to move in a horizontal direction to the left when: $W_A = 10$ N, $W_B = 5$ N, $\mu_{cd} = 0.4$, and $\mu_{ab} = 0.2$.

Understand the Problem

Any motion of box A in the horizontal direction occurs when the resultant force acting on the system is non-zero and acts to the left (i.e. impending motion). Since friction forces act on both surfaces ab and cd, motion of box A can occur in two ways. Select the two ways by clicking on the proper selections in the list to the right.

Since there are two ways in which box A can move, we will need to determine the force P required in each case. Once we have calculated the force required for the two case, which one is the correct answer? Click on the correct answer to the right.



The smallest force

The largest force

Fig. 3 Governing Mode Identification

Problem Statement

Box A in this system has a weight of W_A while box B has weight W_B . At interface cd, the coefficient of friction is μ_{cd} and at interface ab, it is μ_{ab} . Determine the magnitude of the force P that will cause box A to move in a horizontal direction to the left when: $W_A = 10$ N, $W_B = 5$ N, $\mu_{cd} = 0.4$, and $\mu_{ab} = 0.2$.

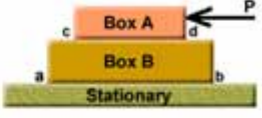
Step 2 - Construct the Free Body Diagram

Select the appropriate forces below and drag them to the correct locations on the free body diagram to the right.

Weight:

Friction:

Normal Reaction:



Case 1 - Only Box A Slides




Fig. 4 Free Body Diagram Development

manner that CBI can evaluate is not possible. Of the possible interactions, the selection and dragging of force vectors onto the correct FBD location is the closest to freehand drawing. Multiple-choice selection from several pre-drawn FBD's is another possibility which is simpler from the program developer's perspective, but which does not fully exercise student analytical skills. The first screen in developing the FBD for the first impending motion mode is shown in Figure 4. The software designer has pre-selected the free-body and left the assignment of the external forces (except the applied force) to the students. In this case, students are to pick one of two forces and drag it onto the correct location on the free-body. In this design, the set of forces to select from is complete. Additional bogus forces could be included among the choices to further develop the student's discriminatory skills.

If an incorrect force is dragged onto the FBD, it flies back to its position in the question and a feedback comment is displayed. Constructive feedback is again used to reinforce the student's choices. An example of constructive feedback for an incorrect force vector selection is shown in

Problem Statement

Box A in this system has a weight of W_A while box B has weight W_B . At interface cd, the coefficient of friction is μ_{cd} and at interface ab, it is μ_{ab} . Determine the magnitude of the force P that will cause box A to move in a horizontal direction to the left when: $W_A = 10\text{ N}$, $W_B = 5\text{ N}$, $\mu_{cd} = 0.4$, and $\mu_{ab} = 0.2$.

Step 2 - Construct the Free Body Diagram

Select the appropriate forces below and drag them to the correct locations on the free body diagram to the right.

Weight:

Friction:

Normal Reaction:

Case 1 - Only Box A Slides

NO! Friction forces act in a direction opposing impending motion. In this case, the motion will be to the left.

Fig. 5 Constructive Feedback Example

Figure 5. In this example, the student has selected the friction vector that points in the wrong direction. The constructive comment made when this choice is selected coaches the student about the concept of impending motion and how friction always opposes impending motion.

This example also shows that the student assigned the weight vector first. The order in which the force vectors are assigned to the free-body is the student's choice in order to simulate the freehand drawing of a FBD as much as possible. Students continue to drag the appropriate force vectors onto the FBD until it is completed as shown in Figure 6. At that time, students are permitted to proceed to the next step of the process. This is done by clicking on the next button in the lower right-hand corner of the screen. If they wish, students can also go back to the preceding step by clicking the previous button.

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4. Equilibrium Equations

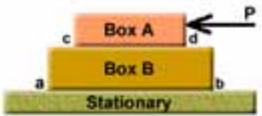
The third step in the process is to have students write the force equilibrium equations consistent with their FBD. Again, designers have a choice of several CBI interactions and methods. Exactly which technique should be used depends upon the secondary goals for this step in the process. In this example, the goals were to have students write the equilibrium equations with a minimum of coaching and to recognize that equilibrium requires the sum of the opposing forces to be equal. These goals were met by having students write one side of the equilibrium equation at a time using a text entry interaction. Figure 7 illustrates the first screen in this process.

Problem Statement

Box A in this system has a weight of W_A while box B has weight W_B . At interface cd, the coefficient of friction is μ_{cd} and at interface ab, it is μ_{ab} . Determine the magnitude of the force P that will cause box A to move in a horizontal direction to the left when: $W_A = 10 \text{ N}$, $W_B = 5 \text{ N}$, $\mu_{cd} = 0.4$, and $\mu_{ab} = 0.2$.

Step 2 - Construct the Free Body Diagram

We can now proceed with the analysis of this free body diagram.



Case 1 - Only Box A Slides

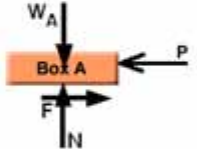


Fig. 6 Complete Free-Body-Diagram

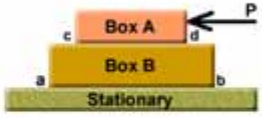
Problem Statement

Box A in this system has a weight of W_A while box B has weight W_B . At interface cd, the coefficient of friction is μ_{cd} and at interface ab, it is μ_{ab} . Determine the magnitude of the force P that will cause box A to move in a horizontal direction to the left when: $W_A = 10 \text{ N}$, $W_B = 5 \text{ N}$, $\mu_{cd} = 0.4$, and $\mu_{ab} = 0.2$.

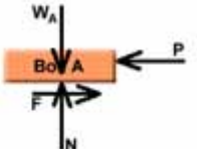
Step 3 - Write the Equilibrium Equations

Enter the left-hand-side of the vertical equilibrium equation in the box below:

W_A



Case 1 - Only Box A Slides



Vertical Equation

Fig. 7 Equilibrium Equation Entry

Students begin the process of writing the vertical equilibrium equations by writing the left-hand-side of the equation. This side can be either the upward acting or downward acting force sum. In this example, the student has elected to write the downward acting sum first. Once the text has been entered, students press the enter key to proceed.

Text entry is one of the more difficult CBI interactions to program because of the many possible

ways users can correctly enter text. In this example, students can either begin equation entry with the downward acting sum or the upward acting sum. Designers must also accommodate case sensitivity and mathematical operators (+ and – in equilibrium equations). Hence, there are many paths to a correct answer, each of which must be anticipated by the designer.

Once the left-hand-side of the equation has been entered, it is displayed and students proceed to enter the right-hand side as shown in Figure 8. In this case, students must enter the upward acting force sum to be consistent with the downward acting force sum of the previous step. In this way, students exercise and master the concepts of directional conventions as well as directional consistency.

Students now proceed to write the horizontal force equilibrium equation in the same manner as they wrote the vertical equilibrium equation. Again, they can select forces acting to the right or left for the left-hand-side of the equilibrium equation. Students can take either left-acting or right-acting forces as positive as long as they are consistent when writing the right-hand-side of the equation.

Problem Statement

Box A in this system has a weight of W_A while box B has weight W_B . At interface cd, the coefficient of friction is μ_{cd} and at interface ab, it is μ_{ab} . Determine the magnitude of the force P that will cause box A to move in a horizontal direction to the left when: $W_A = 10\text{ N}$, $W_B = 5\text{ N}$, $\mu_{cd} = 0.4$, and $\mu_{ab} = 0.2$.

Step 3 - Write the Equilibrium Equations

Enter the right-hand-side of the vertical equilibrium equation in the box below:

Case 1 - Only Box A Slides

Vertical Equation

$W_A =$

Fig. 8 Equilibrium Equation Completion

Figure 9 shows the screen when all the equilibrium equations have been written and this step of the process is complete. Observe how the lower right-hand panel of the screen is being used to develop the solution in a manner similar to a handwritten solution. This is done

intentionally so that students can observe and learn how to format and organize their work.

As in all steps of the solution process, navigation buttons that allow students to proceed to the next step or return to the previous step appear as each step of the solution process is successfully completed. These buttons are shown again in Figure 9.

6. Equilibrium Equation Solution

Now that the equilibrium equations have been written, students can proceed to substitute the appropriate data and solve the algebraic system for the magnitude of the applied force P . In this example, the goal is to coach students through the process of solving the equation system (first solve the vertical equation and then the horizontal equation) and to have students perform the actual calculations. The text entry interaction was selected for this purpose because it forces students to calculate the answer rather than select from a list of potential answers.

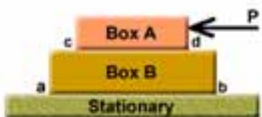
The first screen in this step of the process is illustrated in Figure 10. In this step, students are to enter the value of the normal force N magnitude. Inspection of the vertical force equilibrium equation tells the students that this magnitude equals the weight of block A. This weight is contained in the problem statement. Figure 10 also displays the constructive feedback that results when students enter an incorrect answer at this point. In addition, this screen demonstrates that the text entry box is automatically awaiting a correct answer entry by the students. The software does not allow students to proceed until they have entered the correct answer.

Problem Statement

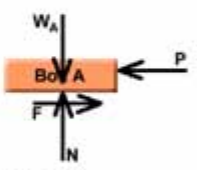
Box A in this system has a weight of W_A while box B has weight W_B . At interface cd, the coefficient of friction is μ_{cd} and at interface ab, it is μ_{ab} . Determine the magnitude of the force P that will cause box A to move in a horizontal direction to the left when: $W_A = 10 \text{ N}$, $W_B = 5 \text{ N}$, $\mu_{cd} = 0.4$, and $\mu_{ab} = 0.2$.

Step 3 - Write the Equilibrium Equations

We can now complete the solution for case 1.



Case 1 - Only Box A Slides



Vertical Equation
 $W_A = N$

Horizontal Equation
 $P = F$

Fig. 9 Completion of Equilibrium Equation Development

Once students have calculated and entered the correct normal force, they must next apply the horizontal equilibrium equation and the definition of the static friction coefficient at surface cd to proceed. The screen following this step is shown in Figure 11. The magnitude of the applied force P when block A moves relative to block B is clearly noted and the navigation buttons reappear.

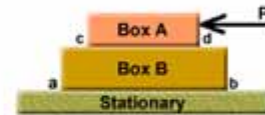
Problem Statement

Box A in this system has a weight of W_A while box B has weight W_B . At interface cd, the coefficient of friction is μ_{cd} and at interface ab, it is μ_{ab} . Determine the magnitude of the force P that will cause box A to move in a horizontal direction to the left when: $W_A = 10 \text{ N}$, $W_B = 5 \text{ N}$, $\mu_{cd} = 0.4$, and $\mu_{ab} = 0.2$.

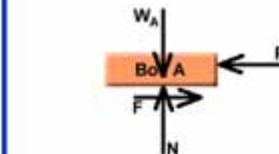
Step 4 - Substitute & Solve

According to the vertical equilibrium equation, the normal reaction force, N , is:

N Sorry! The normal force must equal the weight of box A.



Case 1 - Only Box A Slides



Vertical Equation

$$N = W_A$$

Horizontal Equation

$$F = P$$

Fig. 10 Initiation of Equilibrium Equation Solution Step

When students select the Proceed navigation button the program goes to the FBD development step for the mode where blocks A and B move together relative to the fixed surface. The process of analyzing this second impending motion mode follows that applied to the first mode. The final screen at the conclusion of analyzing the second impending motion mode is shown in Figure 12.

Problem Statement

Box A in this system has a weight of W_A while box B has weight W_B . At interface cd, the coefficient of friction is μ_{cd} and at interface ab, it is μ_{ab} . Determine the magnitude of the force P that will cause box A to move in a horizontal direction to the left when: $W_A = 10 \text{ N}$, $W_B = 5 \text{ N}$, $\mu_{cd} = 0.4$, and $\mu_{ab} = 0.2$.

Step 4 - Substitute & Solve

Applying the definition of the coefficient of friction, the friction force, F , is:

N

The horizontal equilibrium equation now tells us that the force P required to cause box A to move alone is:

N

Hence, the force required for motion to begin if only box A moves is 4 N.



Case 1 - Only Box A Slides

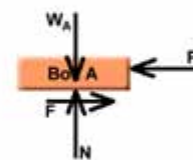


Fig. 11 Completion of Motion Mode 1



6. Problem Review

The screen following the complete analysis of both impending motion modes is shown in Figure 13. The purpose of this screen is to bring the problem to a conclusion, remind students that the correct mode is the one requiring the

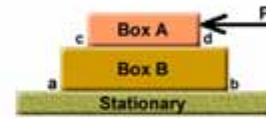
smallest applied force P , and to assist them in developing their discrimination skills. CBI designers can accomplish these goals in a variety of ways. In this example, the designer has elected to use a short summary statement to conclude the problem and state the final answer.

Reasonableness checking was not done in this example since students must always enter the correct answer at each step in the process. Rather, one of the secondary goals of this problem is to develop student engineering design skills including discriminating between multiple

answers. By the time students have completed the solution to the original problem, they may have forgotten which of the two solutions governs. The final screen reviews the two solutions

Problem Statement

Box A in this system has a weight of W_A while box B has weight W_B . At interface cd, the coefficient of friction is μ_{cd} and at interface ab, it is μ_{ab} . Determine the magnitude of the force P that will cause box A to move in a horizontal direction to the left when: $W_A = 10$ N, $W_B = 5$ N, $\mu_{cd} = 0.4$, and $\mu_{ab} = 0.2$.



Step 4 - Substitute & Solve

Applying the definition of the coefficient of friction, the friction force, F , is:

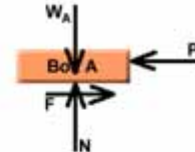
3 N

The horizontal equilibrium equation now tells us that the force P required for box A and B to move together is:

3 N

Hence, the force required for motion to begin when box A and B move together is 3 N.

Case 2 - Boxes A & B Slide

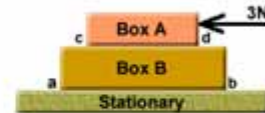


$P_2 = 3$ N

Fig. 12 Completion of Impending Motion Mode 2 Analysis

Problem Statement

Box A in this system has a weight of W_A while box B has weight W_B . At interface cd, the coefficient of friction is μ_{cd} and at interface ab, it is μ_{ab} . Determine the magnitude of the force P that will cause box A to move in a horizontal direction to the left when: $W_A = 10$ N, $W_B = 5$ N, $\mu_{cd} = 0.4$, and $\mu_{ab} = 0.2$.



Conclusion

Box A will begin to move at the smallest magnitude of force P . The second case where **boxes A and B remain affixed** to one another will therefore occur.

$P_1 = 4$ N

$P_2 = 3$ N

Fig. 13 Problem Review

and reminds students of the governing solution. This screen also teaches students that simply calculating a number does not complete a design. Rather, one must apply critical thinking skills to engineering designs.

7. Conclusions

One of the biggest impediments to using CBI is the limited ways in which students can interact with the materials. CBI designers must carefully consider the goals of each step of a learning program and find ways to accomplish these goals within the confines of CBI interactions.

This paper has illustrated the application of a learning goals oriented approach to CBI learning modules for a typical engineering fundamentals course, Statics. The overall goal of the CBI module presented in this paper was to demonstrate the successful application of an analytical process as a means of helping them learn the process. Several secondary goals were also addressed by this example. At all points in the example, CBI interactions were used that best met the goals at that point.

A secondary result of this approach to CBI design is the use of several different methods of student interaction. Variety as well as interactivity in a CBI learning module is essential to maintaining user interest.

The example presented in this paper demonstrates the use of three common CBI interactions, multiple-choice, text entry, and drag and drop. They were used to meet the learning goals at various points in the analytical process. Multiple-choice was used where the choices were simple and did not require any graphical, equation, or numerical development. Although not a perfect match, drop and drag was employed to simulated freehand graphical analysis. Finally, text entry was employed where higher-order skills of equations and numerical development were required.

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