COLLABORATIVE, GOAL-ORIENTED MANIPULATION OF ARTIFACTS BY STUDENTS DURING STATICS LECTURE

Paul S. Steif [1], Anna Dollár [2]

Abstract - *To apply Statics effectively, students must link the concepts and symbols of Statics to the mechanical paraphernalia of engineering. Forming these links is challenging, however, because the interactions between inanimate objects are difficult to perceive. We have consequently revamped Statics instruction so as to introduce the major concepts of Statics - forces, moments, couples, static equivalency, free body diagrams and equilibrium – using simple objects on which students can exert forces and couples with their own hands. Small groups of students manipulate objects in lecture. To guide student interactions with the objects, to lay bare key concepts, and to acclimate students to the representations which are common in mechanics, we have devised multiple choice concept questions implemented through Powerpoint Presentations. Concept questions involve little or no calculation and focus on understanding of concepts. Moreover, insight into the concept questions can be obtained through manipulation of the objects and peer-to-peer discussions.*

Index Terms - Classroom Demonstrations, Concept Questions, Modeling, Statics.

INTRODUCTION

In recent papers [1-2], we have argued that a new instructional approach needs to be adopted if students are to successfully apply Statics in the analysis and design of real systems and structures. It appears that students fail to relate the symbols of Statics to the actual forces which they represent. The meaning of the symbols of Statics is so elusive because students have trouble envisioning the forces that relatively rigid, inanimate objects exert on one another, e.g., the forces between contacting parts of a machine. Rather than follow the approach of most textbooks, we have re-focused the initial phases of Statics instruction away from machines and structures and onto situations in which students experience the forces directly or can observe their effects.

We also believe that students can build their knowledge more securely if individual concepts of Statics are decoupled from one another and presented sequentially. This is preferable to confronting students immediately with problems that draw on many concepts, although eventually they must be able to solve such problems as well..

Thus, our teaching of Statics sequentially treats its major concepts - forces, moments, couples, static equivalency, free body diagrams and equilibrium - using simple objects on which students can exert forces and couples or considering the balance of the human body. However, to take maximum advantage of experiences with objects, students must be prompted to contemplate key questions and given the opportunity to explore them collaboratively and learn from each other.

This is accomplished through what we term Learning Modules, which include classroom desktop experiments or demonstrations (the objects), PowerPoint Presentations and, often, Concept Questions. Students manipulate the objects, maintaining them in equilibrium, or creating their motion or deformation, in pursuit of various goals. The instructor controls PowerPoint Presentations which explore ideas introduced by the experiments and facilitate the transition from real objects to their models and representation with symbols. Presentations typically contain Concept Questions (CQ's), akin to Mazur's ConcepTests [3]. These are multiple-choice questions that assess student understanding of concepts, and which require little or no analysis. Students vote for the different answers, which are color coded, by raising an index card of the appropriate color. Often, students are encouraged to consider (or reconsider) a question after discussing it with peers or after manipulating the object.

Through Learning Modules we seek to help students: establish connections between tangible physical systems and the symbols that represent them, see that physical experiences can be rationalized with Statics, and use their intuition about physical systems to critique and make sense of the results of their analysis. Here we describe two Learning Modules that demonstrate the interplay between experiences with objects and the guided, interactive contemplation of those experiences through the prism of Statics.

BALANCING AN L SHAPED MEMBER

The first example focuses on the conditions to maintain a body in equilibrium and the combined effect of forces and couples. This module utilizes an L-shaped object which we have employed for several different modules. Each group of 3 students has such an object to manipulate.

Here, we consider the various means by which the L can be supported when the plane of the "L" is oriented horizontally. The first phases of the Module ask questions regarding the prospects of supporting the object with fingers

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underneath different points of the L. First, students are asked whether the L could be supported by a single finger and whether two fingers are sufficient. The notion of the center of gravity thereby arises in a natural way.

When three fingers are used, the forces exerted by them are found to be dependent not only on the balance of vertical forces, but on the balance of moments about different axes as well. An example of a concept question focusing on this is shown in Figure 1.

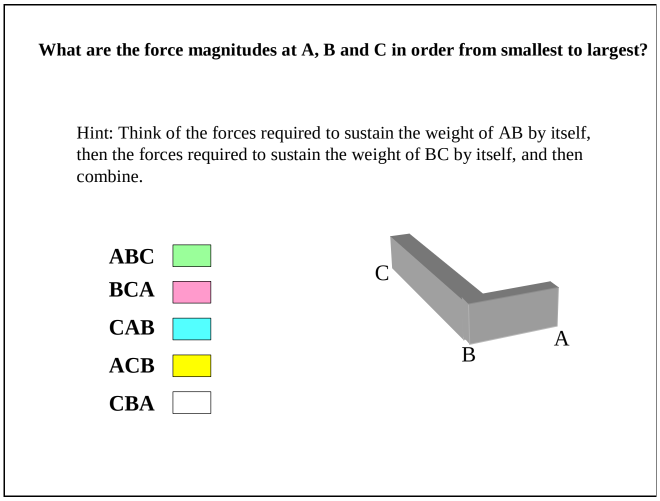

FIGURE 1

We use one part of the L in a previous module, which is described in detail in [1], that deals with couples and equivalent loadings (Figure 2). In that module students have been acquainted with the concept of a couple, as a combination of two or more forces with a net tendency to rotate. Furthermore, they are familiar with applying a couple through a nutdriver attempting to turn a nut (or a screw driver turning a screw).

FIGURE 2

This prior experience prepares them to consider the question depicted in Figure 3. While it is difficult for most students to answer the question solely based on theoretical considerations, they can experiment with the "L" and the nutdriver (Figures 4 and 5).

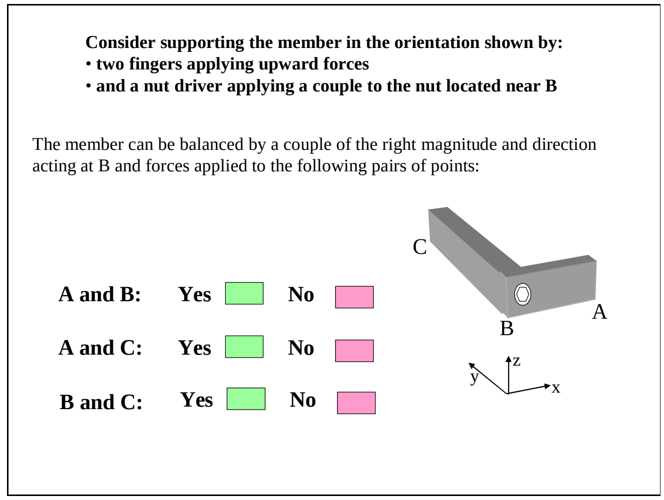

FIGURE 3

FIGURE 4

FIGURE 5

Once a pair of support points is chosen, students can further consider the Concept Question depicted in Figure 6. This question involves the recognition of the direction of the couple in question, (M_x, M_y or M_z), and its sign. For many students, the sign of this moment may not yet be readily determined on the basis of theoretical consideration. However, students can both imagine the experience of balancing the body in this way and they actually balance it (Figure 5), both approaches leading them to the correct sign.

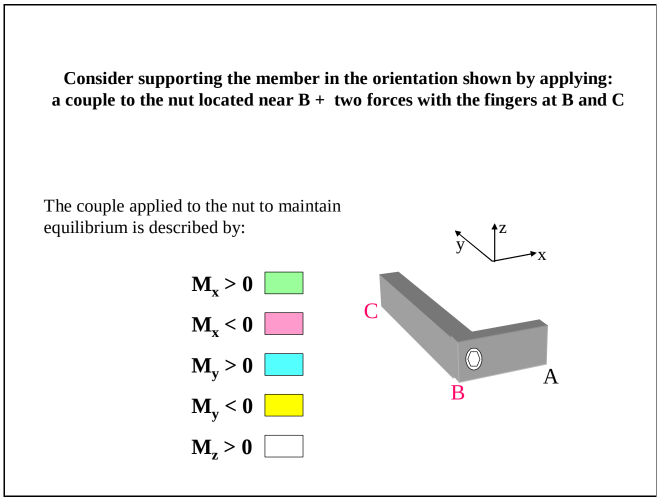

FIGURE 6

The magnitude of the couple requires a consideration of equilibrium. It is here that the summation of moments, including contributions of couples and of forces, is introduced in Figure 7.

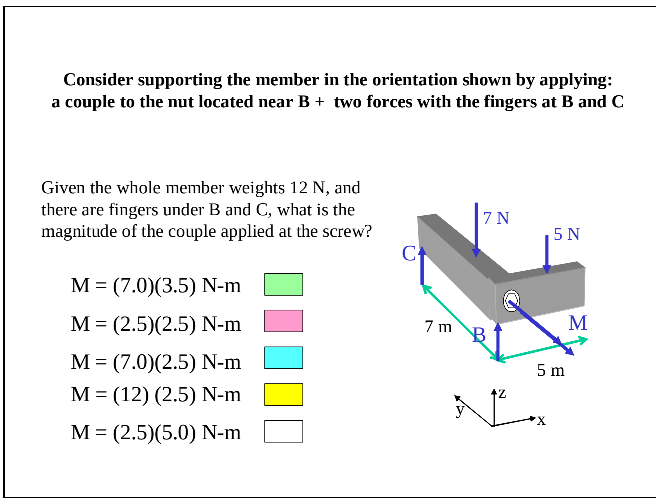

FIGURE 7

While the inferred magnitude cannot be verified by the sensation of the applied couple, the direction of the couple is seen to be consistent with their earlier intuition or sensation. The force values, which can be inferred from force equilibrium (Figure 8), can be also compared in relative magnitude to the forces as experienced by the fingers.

After this experience, students can be asked to consider the alternative means of supporting the L by two fingers (Figure 9). They now have the tools to arrive at results via theoretical considerations, which can again be compared, at least in sign and relative magnitude, with forces and couples as directly experienced (Figure 5).

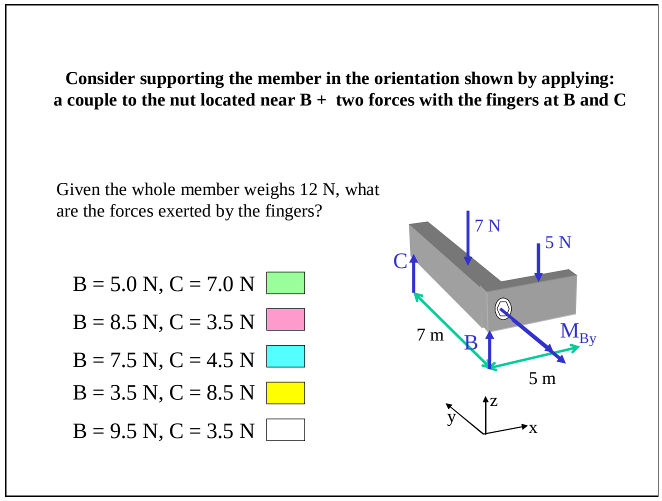

FIGURE 8

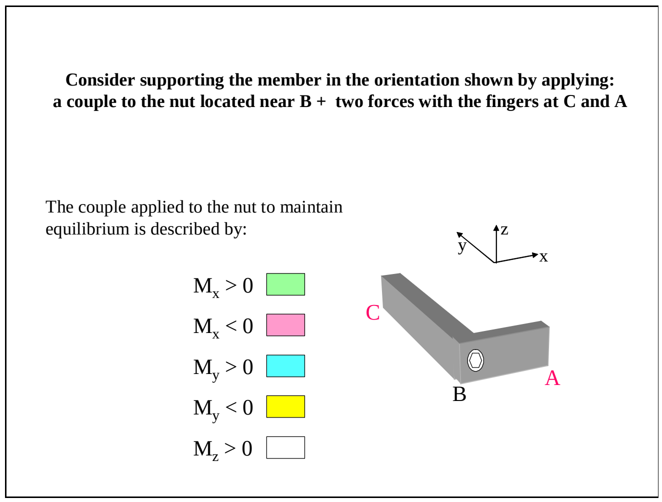

FIGURE 9

HUMAN BODY EQUILIBRIUM

Besides manipulating objects, students like all humans have great intuition with regard to the conditions necessary to maintain balance of their own bodies. In addition, in any situation of balance, they experience directly the forces exerted between the body and the floor, wall or other contacting objects. As one example, one can use the human body balance to address again the forces and couples which maintain equilibrium in three dimensions. In Figure 10, we depict a person standing on a single foot and pressing against the wall with the opposite hand. This and other problems regarding human body balance naturally have the advantage that each student can experiment with the physical situation on his/her own.

Prior to addressing this problem, we introduce a notation to represent the body and forces exerted on it. We give students some experience using this notation by solving simpler problems, such as a body simply leaning forward or backward. Then, to address the problem of pressing with one hand against the wall, a series of questions is asked. These questions prompt students to think about all the loads acting on the body (the couple on the foot is not one that most students appreciate initially). Then, students consider the consequences of each of the conditions of equilibrium; these relate the forces to one another, and also dictate the position of the body relative to the foot.

Figure 11 shows Concept Questions dealing with equilibrium equations. One equation of equilibrium remains unresolved and suggests the presence of the couple on the foot, which students, upon greater reflection can indeed experience as exerting a twist on the leg.

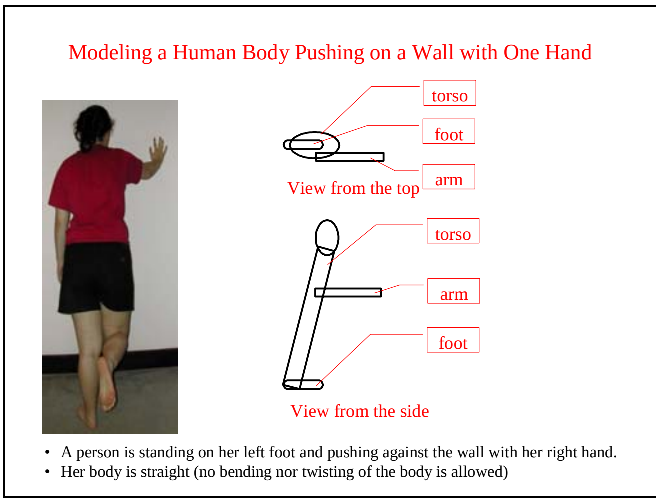

FIGURE 10

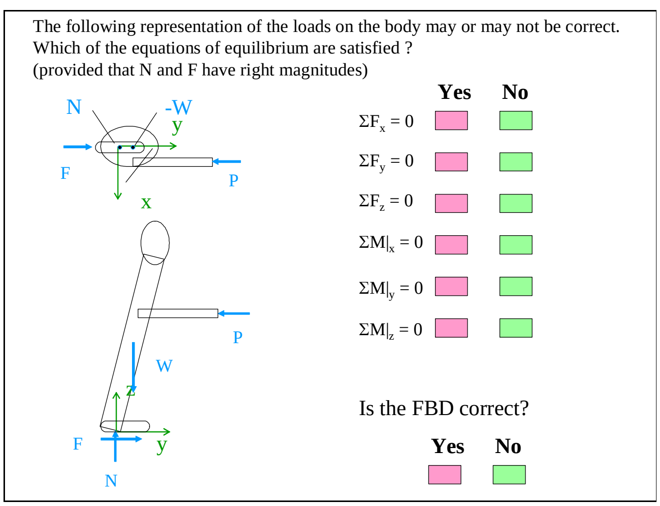

FIGURE 11

Balance of a human body also provides an excellent context to address what is perhaps the most significant misconception regarding friction. Too often, students think that the friction force is always equal to the friction coefficient times the normal force. Instead, students should acquire the notion that a force arising from friction resists motion and attempts to maintain equilibrium, but has an upper limit given by the friction coefficient times the normal force. This misconception is confronted in this Learning Module with a physical situation familiar to virtually all students: attempting to push a heavy object.

The module begins with the basic question of what factors control the force that an individual can apply to an object (Figure 12).

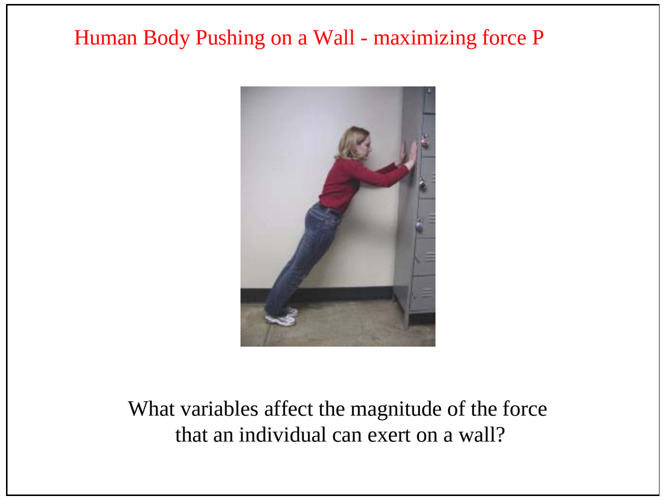

FIGURE 12

After identifying body position, friction between the shoe and floor, and strength of the individual as factors, each is addressed in sequence. First the student is asked to contemplate whether the force can be altered while holding the body position fixed (Figure 13).

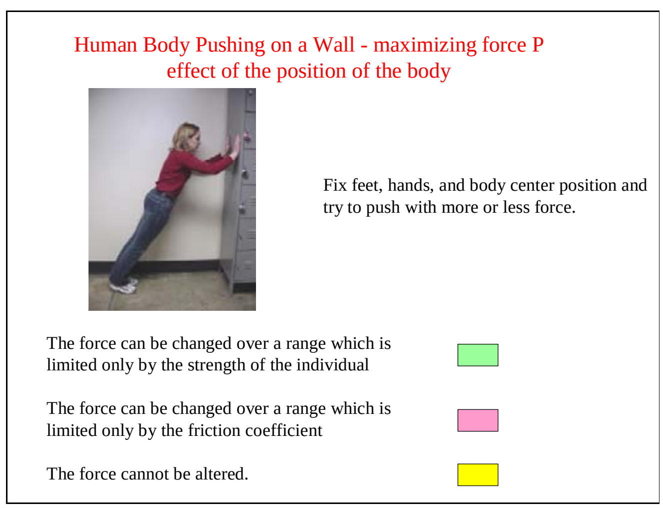

FIGURE 13

By encouraging the student to experiment with a given floor (holding the friction between the shoes and the floor constant), the student comes to see that only by adjusting the center of the body can the force be altered.

Once students recognize that body position affects the force, they can be prompted to quantify this dependence (Figure 14). Now they must resort to the symbols and concepts of Statics. If there are a number of students who do not choose the right answer, they can be explicitly recommended to consider the implications of moment equilibrium.

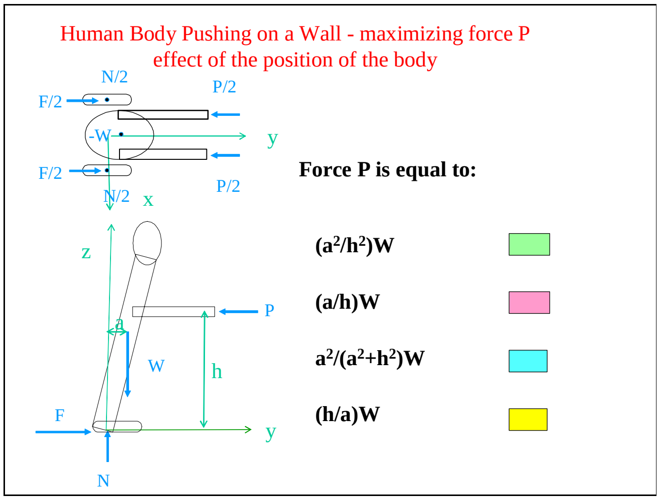

FIGURE 14

Now, once it is seen that the force equals Wa/h (from moment equilibrium), increasing the force is seen to be explicitly tied to increasing the ratio a/h. One naturally wonders whether there is any upper limit on the force that can be applied since one could continue to move the feet back or lower the hands.

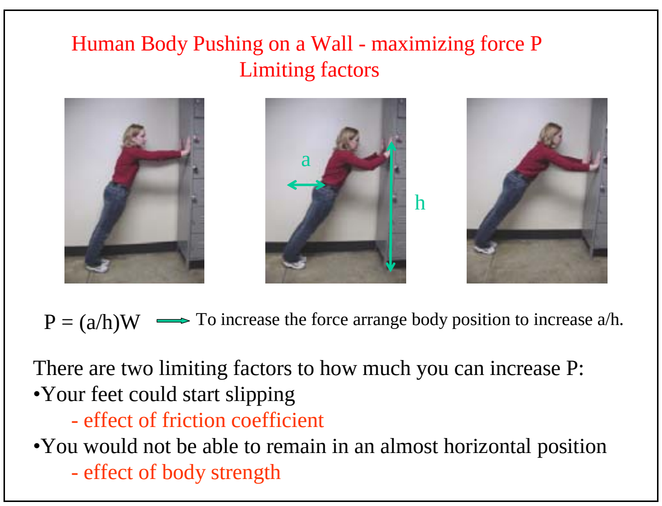

FIGURE 15

Students readily see that increasing a/h is eventually interrupted by either slippage at the feet or lack of body strength required to maintain a tilted position (Figure 15).

To bring friction more explicitly into the analysis, we next turn the problem around, and we ask how the maximum possible force changes if the friction coefficient is increased or decreased, assuming variable (Figure 16) or fixed body positions (Figure 17). Students are again allowed to experiment or to think about the situation.

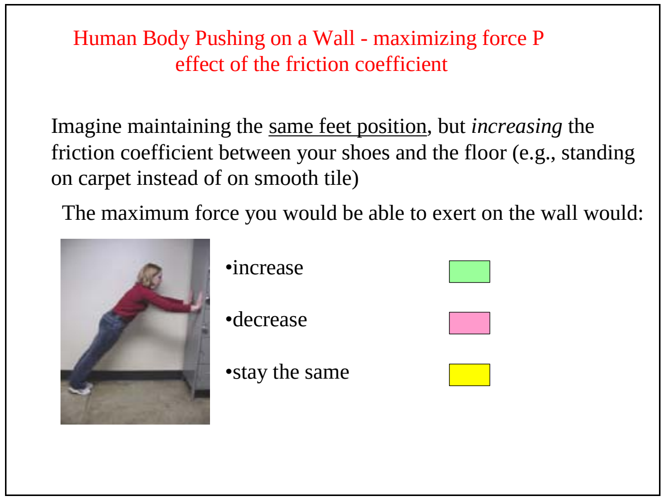

FIGURE 16

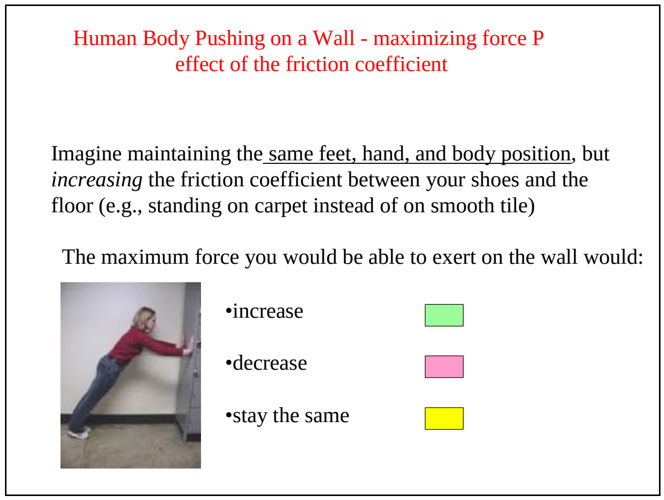

FIGURE 17

After responding to these questions, we turn to consider what equilibrium has to say about the force which can be applied generally, not necessarily at the instant at which the body slips (Figure 18). Among the possible answers to the question of what is the horizontal force, we intentionally place before the student the primary misconception: that the friction force is equal to the friction coefficient times the normal force (μW in this case). To convince students of the result, we would next go through the equations of force equilibrium, which dictate that the friction force must, indeed, equal P and the normal force must equal W.

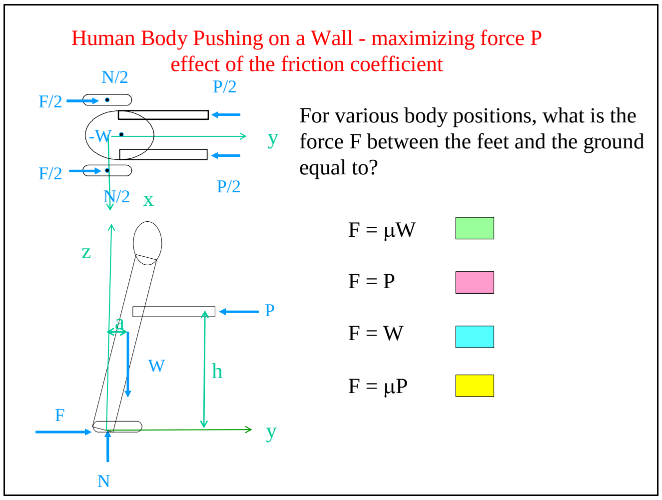

FIGURE 18

Then, the friction condition $F \leq \mu N$ is brought up for discussion. Provided this learning module is used after at least the first lecture on friction, students have seen this relation (as they have in physics), although the meaning of the inequality is often not grasped. Hence, we follow up the question shown in Figure 19. This draws together their recent thinking of how the friction coefficient can change the *maximum* possible for force with findings based on equilibrium (Figure 14).

Clearly, we wish for students to recognize that the body position determines the force, and the friction coefficient is irrelevant, although it limits the extent to which the body can be re-arranged to provide for ever-greater force.

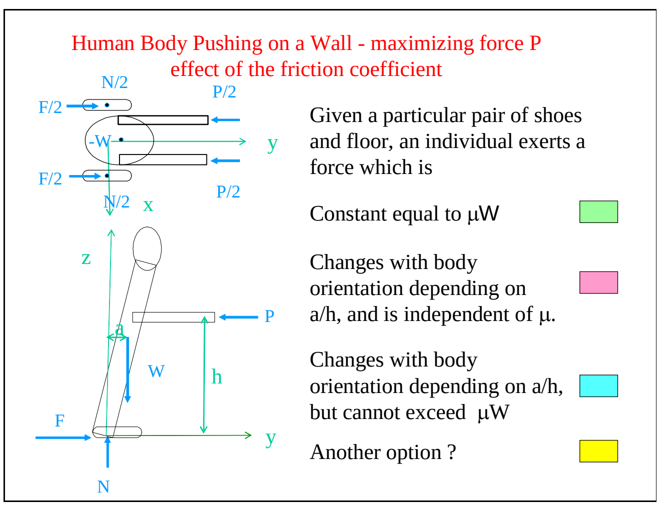

FIGURE 19

The role of strength provides for additional stimulating discussion, which is probably most fruitful in classes that have considered axial loading and bending (Figure 20).

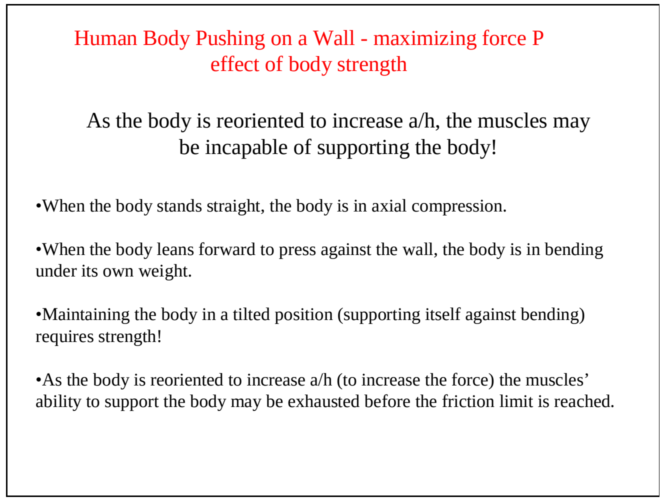

FIGURE 20

SUMMARY

The two examples shown are representative of a number of similar learning modules that were implemented in our classrooms during the 2002-2003 academic year, in classes of approximately 100 and 30 students. While a formal evaluation has not yet been conducted during this year in which many of these materials were being developed and used for the first time, surveys of students elicited very positive responses. Students appreciate relating Statics to their everyday experience in such a tangible way, as well as testing, and correcting, their understanding through Concept Questions as lecture proceeds. We continue to refine and expand these materials for our own use and to prepare them so as to be readily usable by other instructors.

ACKNOWLEDGMENT

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