UNDERSTANDING INTERNAL LOADING THROUGH HANDS-ON EXPERIENCES

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Introduction

Statics is ultimately of value because it is used, along with other theories, to predict the behavior of real objects. Unfortunately, Statics instruction traditionally focuses on mathematical manipulations, often leaving the student unable to perceive the presence of a force or moment in a real life situation. Moreover, students cannot learn Statics in a very abstract way and then be expected in later courses to apply those ideas to real artifacts. Along with many faculty, we are disappointed with the extent to which students are able to use Statics in the analysis and design of mechanical systems and structures which they confront in their subsequent education[1], and later in their professional careers. We believe that physical experiences with forces and moments that act between, or within, objects must be part and parcel of the very earliest exposure to Statics.

Statics is taught traditionally in the context of rigid bodies, and it is logically consistent with rigid bodies. However, Statics is mostly to be used in circumstances in which the motion of objects, or their deformation and failure, is in question. Thus, students must ultimately learn to couple the ideas of Statics with motion and deformation. Moreover, from a pedagogical viewpoint, the most important ideas of Statics – forces and moments and how they arise between connected members - are truly understood only by reference to motion and deformation. While Statics does not concern itself with the time dependence of motion (velocity and acceleration), it does implicitly depend on distinguishing between translations and rotations in different directions. Only by contemplating motions in various directions, can one rationalize the force and moments that may or may not exist between objects that are connected (or parts of the same body). In addition, forces and moments are measured in engineering practice only by the motions or deformations they cause.

Statics utilizes a single principle of physics (equilibrium), which it elaborates substantially and applies to model real systems for the purposes of design. Since students have trouble applying the principle of equilibrium, rather than understanding the principle itself, we see great relevance in Reif's [2] idea of the importance of interpreting scientific and engineering quantities in various contexts.

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Conventional Statics instruction has been successful in teaching students to write and solve equilibrium equations based on a known free body diagram, and to construct free body diagrams for textbook problems in which the forces and moments at supports and connections are largely implied by standard symbols in the problem diagrams. However, where Statics is finally relevant to engineering practice in the analysis and design of mechanical systems, instruction has been notably unsuccessful. Students cannot go beyond textbook problems to apply Statics to practical situations, and they cannot take advantage of their physical intuition to rationalize and anticipate the results of Statics. In our view, the lack of experience with physical reality is the single greatest impediment to students' acquiring Statics as a tool to be used in practical engineering tasks.

In physics education much motivation for improvements has come from the work of Halloun and Hestenes [3] who argued that students bring to physics courses ideas and intuition about physical phenomena which are often at odds with scientific understanding, but which traditional physics courses do little to dispel. One element of reform has been the recognition that passive learning through only lectures is not effective. For example, Mazur [4] breaks up lecture period and has students focus attention on qualitative problems and explain their ideas to one another. It has also been recognized that students gain from hands-on activities in which they can discover principles on their own. There has been some appreciation that similar approaches may benefit students in engineering courses, for example demonstration labs for small groups in fluid mechanics [5] and an experiment based on stacked cubes for structural mechanics [6]. We argue that by working in groups and seeing their notions of force and moment in the context of physical objects, students are actively engaged and have the opportunity to benefit from each other's insights as they seek to ferret out important misconceptions which may prevent their further progress.

Instructional Innovations

We propose instructional innovations that ground students' understanding of forces and moments acting between bodies and/or segments of a body in physical reality by *increased reference to sensory information: the sense of touch, the perception of motion and deformation and experiences with actual artifacts*.

The most immediate means of recognizing and discriminating between different types and directions of forces and moments is through *the sense of touch*. This ability to feel forces and moments must be mastered prior to recognizing interactions between connected bodies and/or within bodies. We seek to empower students to:

- appreciate the distinct feel of forces and moments associated with maintaining a grasped object in equilibrium
- associate directions with the feel of different forces and moments needed to maintain an object in equilibrium

We want to enable students at the very earliest stage to recognize and classify different types of forces and moments by *relating them to their associated motions and deformations*. More specifically, we want students to:

- appreciate interactions as imparting or resisting different types of motion or deformation

- understand internal loads by reference to the associated deformations

We are proposing *hands-on experiences with simple artifacts* that are tailored to give students opportunities to model actual systems using Statics. This should build the foundation for a design approach that can truly utilize all the engineering science which students are learning.

Instructional Activities

Here we describe a collection of student group activities and classroom demonstrations that are aimed at improving students understanding of forces and moments as interactions between objects and/or between segments of a body. These activities recognize the value of students sharing thoughts during experiments with peers and instructors. The social environment of learning is critical – in addition to solitary, individual work, students should be able to debate, discuss, and critique each other's work.

1. Motion and deformation related to forces and moments

This set of activities gives students experience in categorizing different kinds of motion and identifying the motions which various forces and moments are capable of imparting or resisting. The simplest activities will involve two students gripping a small body, with one student actively attempting to impart motion. The second student will declare the type and direction of motion that the first student is attempting to impose, as well as the direction of the force or moment that he or she is exerting to resist the motion. More advanced activities involve one student gripping a rod at one end, and the second applying loads to the other end in various directions. The student gripping the rod must describe the actions he or she is exerting to maintain equilibrium. Activities will also feature students stretching, twisting and bending bars and relating those deformations to the applied loads.

2. Internal Loads

This set of activities would enable students to gain greater insight into the very presence of internal forces and moments, into how they are related to applied loads and how they are to be elucidated for simple bodies.

2a. Proof of presence of internal forces and moments:

Two identical highly deformable shafts (foam rubber) are held side-by-side and twisted at their ends in the same way by two pairs of students. Each student is told to maintain the orientation of his or her end of the shaft. A fifth student approaches and cuts one of the shafts somewhere along its length. The two parts of the cut shaft is seen to untwist, suggesting that previously there was "something" acting across the cut surface. The fifth student returns and, while the four students are maintaining the original orientation of their ends of the shaft, applies torques to the neighboring ends of the cut segments, bringing them to the same orientation. The fifth student is seen to be functioning as the internal torque.

2b.Relating applied loads and internal loads:

These laboratory activities are aimed at getting students to see that applied loads and internal loads are distinct, but can be related. For axial loading a set of springs stacked with separating plates to which weights can be applied will be used. Using rulers, students will measure the deformation of the individual springs and infer the internal forces in the springs. The applied forces are given by the known applied weights. The observed internal forces will be compared to those predicted using free body diagrams of various segments of the assembly. For torsion and bending a set of solid and hollow plastic bars will be used to which weights will be applied creating torsional and/or bending moments at various locations along the axis of the bar. Using compasses and rulers students will measure the angles of twist and/or deflections of the individual segments of the bar and deduce the internal loading acting in them. The applied moments will by computed using the known applied weights and moment arms. The observed angles of twist and/or deflections will be compared to those predicted using free body diagrams of various segments of the bar.

2c. Determining internal forces and moments:
This laboratory activity is aimed at giving students experience in setting up the free body diagrams necessary to finding internal loads in actual artifacts. Students will use simple hand held artifacts, for example, a shovel on which the blade supports a mass, studying first their overall equilibrium. They will then be asked to contemplate the loads that keep a designated part of the artifact in equilibrium. Students will set up an appropriate free body diagram and calculate internal forces and moments. They will also consider the remaining part of the artifact. Similar activities will be carried out with the simple mechanisms, now with the goal of determining internal forces and moments within various members.

Summary

Internal loading is a concept that students traditionally have difficulty comprehending - they too often fail to relate internal forces and moments to applied external loads. We propose instructional innovations that ground students' understanding of forces and moments acting between bodies and/or segments of a body in physical reality by increased reference to sensory information: the sense of touch, the perception of motion and deformation and experiences with actual artifacts. This paper describes a set of activities aimed at helping students understand this concept with visual displays, hands-on experiments, and use of actual artifacts. These activities help students gain greater insight into the very presence of internal forces and moments, and appreciate that applied loads and internal forces/moments are distinct but can be related. They are aimed at helping students gain experience which is necessary in finding internal loads in actual structural members.

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