Enriching Statics Instruction with Physical Objects

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Introduction

A student who succeeds in a statics course has the ability to analyze basic mechanical aspects of unfamiliar mechanical systems using the principles and methods of statics. The ability to apply learning to solve new and different problems is termed transfer by cognitive scientists.

A variety of factors affect transfer. Most relevant to the present work is the recognition that the depth of the initial learning affects significantly the ability to transfer. Depth of learning is dependent on a number of factors, including: time on task, learning for understanding rather than memorizing facts, having deliberate practice with feedback, recognizing the signals that trigger the usefulness of the knowledge, and the motivation associated with seeing material being useful.

Enriching statics with physical objects is consistent with several of these factors, in particular in promoting learning for understanding and in motivating students. This paper describes two means taken to enriching statics with physical objects. First, we have devised a set of laboratory activities which offer physical counterparts to each of the basic concepts of statics. Second, we have made a set of engineered artifacts available for study by students through digital images and other electronic means. In the rest of the paper, we described these enrichments and the experience of implementing them in statics class of approximately 100 students.

Physical counterparts to basic concepts

A series of laboratories was devised which offered physical counterparts to the following basic ideas: (i) the moment about a single axis due to a force in three dimensions, (ii) the relative motions permitted at standard connections, (iii) free body diagrams of a body for which students supply all loads necessary to maintain equilibrium and (iv) the motions of, and forces acting between, bodies constituting simple mechanisms. Two of these experiments are described in detail.

To address the challenge of relating forces in three-dimensions to moments, an apparatus was designed (Figure 1) that consisted essentially of L-shaped arm, which pivots about a single axis and which is maintained in a neutral position by a set of springs attached to a frame and to the arm near the pivot point. Forces can be applied via a spring scale to various points on the arm. Such forces cause the body to rotate about the pivoting axis. Attached to the frame is a protractor, which allows the rotation of the body to be measured (rotations up to 10° are allowed).
The body is maintained in a rotated position by two moments: the restoring moments of the springs and the moment due to the applied force. The moment due to the applied force can be calculated by resolving forces and finding perpendicular distances (or using the cross-product). The restoring moment of the springs, which balance the applied moment, can be found from the rotation and geometry of the springs.

Two distinct mechanisms, each of which converts an input force into a very large output force, were designed and constructed for observation and student testing. One of these mechanisms is depicted in Figure 2. Students apply forces to the end of a long lever and measure the orientation of the lever via the mounted protractor. Students measure the extension of the spring that is fixed at one end and mounted to the sliding cylinder at the other. Thus, students study both kinematics (relating the change in lever orientation to the spring extension and statics (relating the force applied to the lever to the spring force). This mechanism exhibits several ideas common to mechanisms, including the motion of a four-bar linkage and the reorientation of a link so that its force, which balances moments at a pivot point, becomes large compared with the input force. This apparatus also allows students to study several common joints, including a pin joint, a pin-in-slot connection and cylinder confined to sliding within a sleeve.

Figure 1. Mechanism for studying moments due to forces in three dimensions.

Figure 2. Mechanism on which students make measurements and conduct kinematic and static analyses.
Artifacts for homework assignments

The followed artifacts were the basis for homework assignments: the rear hatch of an SUV (opened by gas springs), a bicycle rack, a no-twist clamp, a corkscrew, a rail clamp (for securing electronic equipment to a rail), a wing corkscrew, and an exercise machine. In each case students were asked to conduct one or more analyses related to the mechanics of the artifact or the evolving geometry of the artifact. Sometimes additional information as to how the artifact operated was provided. In all cases, students had some means to infer relevant dimensions. In cases of objects readily viewed in a single plane, a length scale was incorporated in the digital image. The student could take measurements from the image with a ruler and compare with the length scale to get actual dimensions. In other cases, actual mechanical drawings were provided. By contrast with problems in statics textbooks, the key points of interest were generally not identified as such. It was up to the student to recognize such points.

Figure 3. Exercise machine that students observe through digital images and video, which is the subject of statics analyses.

An image of one exercise machine considered is shown in Figure 3. Students had access to additional images of the machine, a video of its operation, an explanation of its operation with reference to the parts labeled in Figure 3, and drawings indicating relevant dimensions. In one particular problem, students were given the amount of weight that was being lifted and were asked to determine force that the leg needed to exert to cause the weight to be lifted.
Lessons learned from class use

The course featured 80 minutes of lecture twice a week, one hour of recitation, and a two-hour laboratory period once a week. Laboratories were only held during 5 weeks of the semester. The laboratories, which had up to 35 students at any one time, were generally staffed by two individuals from among the instructor, the graduate teaching assistant and more senior undergraduate students. Students in the class would generally carry out the activities dictated by the lab handout in groups of three. Each student would hand in a laboratory report, which usually included more extensive analysis.

While a number of students acknowledged the potential value of studying the physical systems, this first implementation admittedly left many students frustrated. Students found writing up the laboratory reports burdensome (it was in addition to the weekly homework assignment). The activities to be carried out were perceived to be “cookbook,” with little room for creativity. Students were anxious to make measurements and to get out (labs were in the evenings). This was unfortunate since the major point was not to take measurements. Rather for the case of the experiment depicted in Figure 2, for example, the student was to inspect and follow the relative motions of the bodies constituting the mechanism. For example, when the instructor was present at one particular lab session, he circulated among the groups and found that only upon asking students probing questions did they take the time to think deeply about the mechanism.

It is clear that specific assignments need to be crafted far differently so that students are forced to confront the key features. An improved approach may be to have the student complete work in the lab, with simple deliverables such as answers to a series of questions, and possibly free body diagrams. More in-depth analysis could have readily been incorporated into a subsequent homework assignment, for which such analysis would normally be expected. In addition, in the case of laboratory reports, students feel a heightened license to have one student bear the brunt of doing the work (with others more or less copying). Thus, many students may have largely missed the opportunity to think about what had been observed in lab. In doing homework, a student feel a somewhat greater responsibility for doing his or her own work. Additional effort should also be devoted to allowing students to exploit the mechanisms in other circumstances.

Regarding homework assignments based on artifacts displayed through digital means, students occasionally found such problems to be very challenging. Many also commented on how refreshing such activities were. Students who solicited help in understanding and getting started with such problems were always given guidance; in general, more students needed to be induced to seek such help. It might even have been valuable to talk with students about these problems in recitation (generally occurring on the day before a homework assignment is due). Such help offered within a day or two before the due date is likely to be of value. Students who are capable and want the challenge of figuring out the problems on their own, have probably already done so. Students who are not so capable may very well be satisfied with a low level attempt at analyzing such problems; they will benefit from some insight that will push them to the next level.
Summary

To improve learning of statics and its application to practical problems, we have enriched a statics course through the substantial use of physical objects. These objects include systems devised for class use, as well as artifacts culled from many walks of life. Such objects have the potential of deepening student understanding by making stronger links between the variables and quantities of the theory and the physical entities they represent. Seeing the ideas and methods of statics used in multiple contexts helps the student to recognize how these ideas and methods are relevant in new contexts and applications. Finally, experience with objects and artifacts can be motivating to students. We need to exert additional efforts to craft assignments through which students can gain as much insight as possible from such objects and artifacts.

Acknowledgements: The author thanks Anna Dollar for many stimulating conversations in connection with this work. Support under NSF grant DUE-9950938 and by the Department of Mechanical Engineering is gratefully acknowledged.

Bibliography


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