A New Workstation for Teaching Statics in Machinery

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Introduction

With increasing enrollment and decreasing funds for laboratory equipment, many professors are facing challenges in providing hands-on experience for students in engineering technology. To address these concerns, a simple, inexpensive workstation has been designed, built, and tested to teach students practical aspects of static equilibrium. During Fall 2002, this new workstation was used throughout the semester, and experiments were designed to provide a range of difficulty. Early in the semester, it was used to investigate static equilibrium of a particle; analysis only required summation of forces. Later in the semester, the same workstation was used to study equilibrium of a beam. This required students to add forces and moments to establish equilibrium.

After using the new workstation for one semester, the assessment process has begun. Laboratory reports and conversations with the students have provided feedback on the learning outcomes. Improvements to the laboratory handouts and mechanical enhancements to the workstation have also been identified. These changes will be implemented in future course offerings.

Background

Statics in Machinery is a two-credit laboratory course that covers static equilibrium of particles and rigid bodies, structures, center of gravity, and friction. Lecture size has been expanded to accommodate 24 students, with half of the students in two separate lab sessions. With 12 students taking the lab together, 4 separate workstations were needed to provide hands-on experience in small groups.

The statics laboratory at this institution was already equipped with the following workstations:

- Funicular Polygon
- Basic Roof Truss
- Center of Gravity
- Reaction of Beams
- Simple Moments
- Three Wire Suspension

This equipment, all from the same manufacturer,¹ was purchased when the laboratory was established over ten years ago. Although this equipment is low technology, it provided students practical experience in most of the topics covered in lecture.

To perform a wide range of experiments throughout the semester, each group worked on a different type of workstation, and each group cycles through a series of experiments each week. Experiments were scheduled so that the relevant theory was covered in lecture in advance. With the increased enrollment, additional equipment was needed to allow students to work in small groups, while different groups worked simultaneously on different test stands.

The goal was to obtain a simple test stand, different than the existing equipment, to complement the pre-existing experiments. The workstation was developed based on a novel idea, without considering “off-the-shelf” equipment. In retrospect, after building the new workstation, research was conducted to see if a similar workstation was commercially available. The investigation yielded six manufacturers of mechanical training equipment,^{1,2,3,4,5,6} but their equipment was beyond the current needs for this course. Although one of these vendors² markets workstations for static structural analysis, none of these vendors provide a comparable workstation.

Educational Objectives

One of the objectives was to create an additional workstation that would reinforce the theory and problem-solving in static equilibrium. Many students find the concepts difficult to grasp until they have hands-on experience with real physical systems. Another objective was to fulfill the ongoing requirements for TC2K accreditation by TAC/ABET.

Laboratories were structured to incorporate active learning and small group interaction via hands-on experimentation. This helped to accommodate the learning styles of a diverse student population. Experiments were designed to teach student how to:

- Calculate the forces produced by suspended masses, $W=mg$.
- Draw free body diagrams under several loading conditions.
- Verify static equilibrium by summation of forces and moments in two dimensions.
- Study the effects of loads applied at various angles.
- Use trigonometry to find angles by measuring vertical and horizontal distances.

Before conducting experiments, the relevant theory was presented in lecture. Application of the theory was then reinforced by problem-solving in laboratory exercises and homework assignments.

New Workstation

The new workstation, shown in Figure 1, consists of two plastic peg-boards with a square grid of $\frac{1}{4}$ inch holes on one inch centers. All components were purchased at a local hardware store and a home supply warehouse, and the workstation was built using basic carpentry skills. The peg-boards, 4 feet wide by 2 feet tall, were mounted vertically, parallel to each other, on a base. The frame was constructed from standard wooden two-by-fours, mounted together via self-tapping screws. Plastic feet on the bottom corners of the horizontal members provide a level mounting surface for placing the workstation on a table-top.

Steel rods, $\frac{1}{4}$ inch in diameter and 7 inches long, are inserted through the holes to serve as shafts for pulleys, which are wooden thread spools, $\frac{3}{4}$ inch in diameter. Masses are suspended from the pulleys by strings and hangers. Students can easily change the location of pulleys and orientation of the strings, as well as the amount of weight suspended from each string.

Figure 1. Overall View of the New Workstation

Table 1 lists the cost of items purchased for the prototype workstation. Many of the supplies were already available in the laboratory and fabrication shop, and so the wood, screws, string, weights, and hangers did not need to be purchased. Adding these items as “other hardware,” the total cost would be approximately \$60.

Table 1. Equipment Cost

Item	Total Cost (\$)
Plastic pegboards (2)	20
Steel rod, 6 feet	5
Spools	5
Other Hardware	30
Total	60

Plastic pegboards are relatively new; conventional pegboards are made from wooden particle board. Although the plastic pegboards are slightly more expensive, they are much more durable than particle board. This is crucial because students repeatedly remove and insert the rods, and the edges of the holes have a tendency to chip.

An advantage of this workstation is that all supplies were purchased locally with petty cash, avoiding delays due to purchase requisitions, administration approval, and shipping.

Laboratory Assignments

The workstation was designed to be versatile enough to ensure that each group conducted a different experiment. Laboratory handouts were prepared to give groups general guidelines on procedures to follow, while allowing each group to specify their own geometry and configuration for each experiment. The following two experiments demonstrated particle and rigid body equilibrium.

Static Equilibrium of a Ring: The objective of this experiment was to apply different systems of forces to suspend a ring in a vertical plane, as shown in Figure 2. Three strings pull radially outward on a central steel key ring.

Forces on a Beam: This experiment, shown in Figure 3, employs a wooden beam which pivots about a central fulcrum. Eye-screws, mounted on 2-inch centers on the top and bottom of the beam, allow for various load angles and positions along the beam.

Figure 2. Typical Configuration for Ring Experiment

In each experiment, students decided where to insert the steel rods into the peg boards, producing a variety of mounting configurations unique to each group. By trial and error, students determined the angles and masses needed to obtain static equilibrium. Students selected from an assortment of 1, 5, 10, 20, 50, 100, 150, and 200 gram masses which could be stacked to produce a wide range of loads. After applying several stable loading configurations, the groups analytically verified the conditions of equilibrium for each configuration.

Figure 3. Typical Configuration for Beam Experiment

Learning Outcomes

Outcomes are accomplishment of the educational objective discussed earlier. Outcomes were assessed by laboratory reports and direct instructor/student interaction during the laboratory session. Informal conversations with the students during the lab sessions provided valuable feedback on the workstation. Students made suggestions on improvements for the workstation.

Without exception, all students were attentive, thus confirming the active learning process. Groups of two or three students worked together to obtain equilibrium conditions, thus gaining teamwork skills through small group interaction. Three or four hands were frequently needed to hold the components in place. Groups also worked through the initial frustration of determining how much weight to use. Small masses were not enough to overcome the effects of friction.

As a course requirement, students wrote comprehensive laboratory reports for several of the experiments. Students were given a two-page handout on guidelines for writing laboratory reports. The handout served as a reference for students when writing the reports, as well as a useful guide for the instructor to insure uniform grading for reports written on different experiments. Content of the reports included the experimental procedures, presentation of data, analysis, discussion of results, and conclusions.

Students summarized results using tables and free-body diagrams, and they compared the experimental and theoretical results for each system of loading.

For the first series of experiments in the semester, students were required to write three group laboratory reports. These reports were graded rigorously to provide constructive feedback, and this tended to increase the quality of subsequent reports. For the final series of experiments, students selected one experiment to write a final report. Four laboratory reports seemed to be sufficient for most students to learn how to write good technical reports, without overburdening the workload for a 2-credit course.

In general, the reports indicated that students had a solid understanding of the experiments and the practical aspects of the theory. Because all students did not write reports on this new workstation, a more detailed outcomes assessment is pending. Given a choice, many students opted to write reports on simpler experiments. A more thorough assessment will be possible by requiring everyone to write a report on this workstation.

One of the initial goals was to complement the existing experiments. With the limited use during one semester with two small lab sections, this outcome was difficult to assess. Because it was similar to the other experiments, but not the same, it gave the students a different perspective on static equilibrium. A unique feature of this workstation was that it allowed students to apply forces at a variety of angles. To check equilibrium analytically, students needed to measure angles and resolve the forces into horizontal and vertical components. This activity was valuable because it resembled problems solved in homework assignments, quizzes, and exams. The ability of students to solve these problems may provide a useful assessment tool in the future.

Recommendations for Improvement

After using the workstation for the first semester, several improvements were identified by the students and the instructor. Although the thread spools served as effective pulleys, friction became substantial as loads were increased. Better pulleys, with integral ball bearings, would provide results that are easier to verify analytically.

Slight misalignment of the front and rear pegboards resulted in the shafts being non-perpendicular to the vertical mounting surface. When making the next version of the workstation, an improved assembly procedure is recommended. First, screw the front pegboard into the frame, and then place the rear pegboard on the frame. Before screwing the rear pegboard in place, insert a rod through both pegboards in each of the four corners. This will improve the alignment of holes on each side.

With the workstation in place, more experiments may be developed with simple mechanical components. Tensile forces in strings may be measured using spring-scales, currently used in other test stands. Force measurements could be used to check calculations or to study the effects of friction. In addition to using straight beams, structures and three-force members may be incorporated. Building additional workstations would enable multiple groups to simultaneously work during the same lab session.

Conclusion

The new workstation has proven to be an effective tool for inspiring students with some practical aspects of static equilibrium. After using the workstation for one full semester, several improvements have been identified, including simple mechanical enhancements and changes to the laboratory handout. Because the workstation has only been used for one semester, assessment of the learning outcomes attributed to this workstation is ongoing. More feedback is expected in future course offerings. Based on the initial success, the workstation will be used as a regular part of the statics course in the future.

Bibliography

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Biography

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