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Design and Application of a Beam Testing System for Experiential Learning in Mechanics of Materials

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ABSTRACT

Research shows that students can significantly improve their understanding and retention of topics presented in an engineering course when discussions of theoretical and mathematical approaches are combined with active-learning exercises involving hands-on physical experiments. In this paper, the design and application of a beam testing system (BTS) to promote experiential learning in mechanics of materials are discussed. Students in the experimental group were given the opportunity to verify their analytical predictions on two separate projects by conducting experiments using the BTS whereas those in the comparison group only performed the analysis part. Based on statistical analysis of the performance of the two student groups on a common exam problem, the experiential learning is found to have a positive but limited impact. Moreover, the students' responses to an anonymous survey indicate that the students in the experimental group generally had a higher degree of satisfaction with the class projects than those in the comparison group.

Keywords: Engineering mechanics, modular laboratory, class assessment

I. INTRODUCTION

Engineering education in the early to mid twentieth century relied heavily on the use of physical models and experiments to enforce the topics covered in an engineering course. However, over the years, this important practice was deemphasized as hands-on activities were reduced and relegated to only one or two laboratory courses. Recent research [1–5] on the merit of active student interaction with physical models has revitalized interest in the use of such models, not just in laboratory classes but—more importantly—as an integral part of traditional lecture-based engineering courses. The common element between previous work [1–5] and the present effort is in the use of physical models to enhance learning in traditional lecture based courses in engineering, whereas the difference is primarily in the physical models developed and in the approaches used for their application and assessment. Previous efforts to implement hands-on learning methods in mechanics range from devising tabletop demonstrations [6,7] to establishing an affordable laboratory [8]. In this paper, a portable apparatus is described that can be used for effective demonstrations during lectures and for conducting beam bending experiments by students after class.

A couple of years ago, the authors had an opportunity to design and develop a structural testing system at the Raspet Flight Research Laboratory at Mississippi State University. In one experiment, a whiffletree loading mechanism (WLM), as shown in Figure 1, was designed and used for static testing of a full-scale composite aircraft wing. For simplicity, the wings were mounted upside-down and loaded downward to simulate the lift force distribution. Whiffletree loading is often used in the aerospace industry, with the grade of complexity depending on the number of discrete loading points on the structure and the number of levels in the WLM. Regardless of its loading complexity, such experiments embody many of the basic principles covered in statics and mechanics of materials courses such as the calculations of the magnitude and location of the resultant force associated with a distributed load. This experience provided the impetus for the authors to pursue the topic presented in this paper.

After an initial brainstorming, the authors submitted a proposal and received a grant to pursue a plan to integrate hands-on activities into the mechanics of materials curriculum. A simple beam testing system (BTS) was subsequently designed and built in the summer of 2007 and was introduced into the course on an experimental basis later in the fall when the first author taught two separate sections of mechanics of materials. The teaching of two separate sections of the course

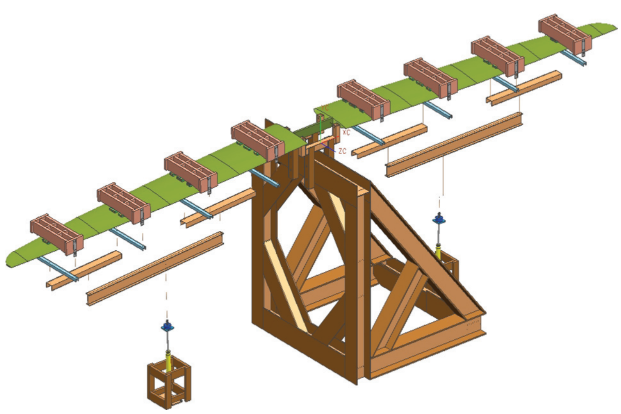


Figure 1. Whiffletree system for static testing of an aircraft wing.

also provided an opportunity to perform a limited formative assessment of the effectiveness of this experiential activity on student learning.

The primary learning objectives of hands-on activities are to enable students to:

1. improve their understanding of beam bending under various lateral loads while considering such factors as the support conditions, cross-sectional geometry, and material properties.
2. enhance their skills in analysis of beam bending problems.
3. learn to model and analyze a simple whiffletree system.

The educational benefits of the BTS are tied to two applications: it can be used as a teaching tool to demonstrate theoretical concepts and example problems in the classroom, and students can use it outside of class to simulate beam problems given as assignments. While the latter application is more consistent with an active-learning activity, the benefits of the former cannot be underestimated. As stated by Schaaf et al., [1] and Campbell [9], classroom demonstrations and hands-on learning methods have been shown to be critically important in the introductory mechanics courses for comprehension of key concepts and retention of information.

II. DESCRIPTION OF THE BTS

The design of the BTS, shown in Figure 2, facilitates the support and loading of simple beams. The entire frame is fabricated from steel square tubing and information regarding the main structural components numbered in Figure 2a is given in Table 1. It consists of two I-shaped support posts that are bolted to a telescoping (horizontal) member at the bottom to form a rigid frame. The two-part telescoping member of the BTS can be used to test beams up to six feet in length. When not in use, the BTS collapses into two halves by taking the horizontal members apart and allowing each section to fold back upon its respective support post. For ease of transport and handling, the BTS has caster wheels. Special mounting brackets on the support posts accommodate the simulation of different boundary conditions. Figure 2b shows a close-up of the clamped condition for a cantilever beam. Machine-cut grooves in the angles allow for adjustment to accommodate a range of beam widths and four bolts are used to fix the beam. The BTS has approximate dimensions of 40″ (height) × 22″ (depth) × 74″ (max length), with a total weight of approximately 80 lb.

Figure 2c also shows a photograph of two students in the process of testing a simply-supported beam. Load is applied manually via the turnbuckle shown in Figure 2c, while its response is measured and recorded using an eight-channel electronic data acquisition system (two Vishay P3 strain indicator units). A 200-lb capacity load cell (Interface SML) is used to take accurate measurement of the applied load and a cable position transducer (Celesco PT1A) with a range of up to 10 in. is used to measure beam deflection. General-purpose uniaxial strain gages with 2-mm (0.079 in.) gage lengths are mounted at selected stations on the test beams to obtain the corresponding normal strain response.

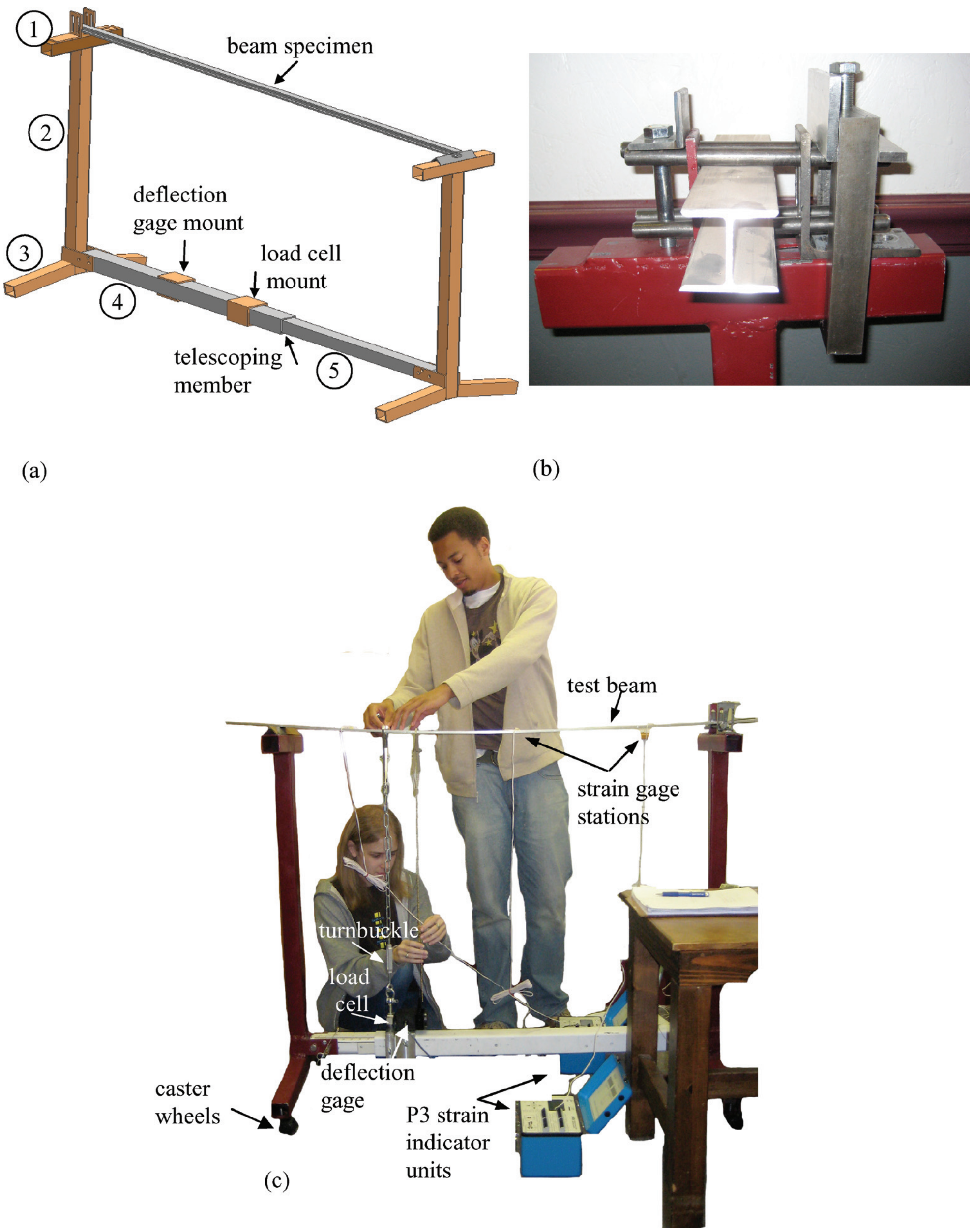


Figure 2. (a) Schematic drawing of BTS (b) clamping device for creating a fixed boundary condition (c) students testing a simply-supported beam.

Member	Description	Cross-section Dimension
1, 2	top rails, vertical posts	2″× 2″× 1⁄16″
3	legs	2″× 2″× 3⁄16″
4	Outer telescopic member	2.5″× 2.5″× 3⁄16″
5	Inner telescopic member	2″× 2″× 3⁄16″

Table 1. Steel square tubing dimensions.

The BTS cost approximately $3500 to build, with over 90% of the funds used to purchase the measurement equipment including the strain indicator units and the load cell. Comparable off-the-shelf units sold by commercial vendors are more than three times the cost of the BTS, and are generally not as portable and modular. The BTS test stand, together with the data acquisition system, comprises a very versatile apparatus that allows for the testing of various beam sizes, cross-sections, lengths, and boundary conditions.

III. STUDENT GROUPS

The two different sections of the mechanics of materials course taught by the first author in fall 2007 offered a natural division of students into separate experimental and comparison groups. Basic statistical analysis was used to compare the level of readiness in the two student groups based on their grades in the prerequisite course, statics, to decide on which section to use as the experimental group. Since students are required to earn a grade of C or better in statics before they are allowed to take mechanics of materials, the range of grades varied from A (4.0) to C (2.0). With the sample mean ($\overline{X}$) and sample standard deviation (S) values of the grades in each group known (see Table 2), the standard deviations of the two populations (i.e., σ_1 and σ_2) were compared using a two-tailed F-test. Since the test statistic ($F = S_1^2 / S_2^2$) was found to be less than the F critical value for 95% confidence interval, the null hypothesis that the two populations have the same standard deviation (i.e., $\sigma_1 = \sigma_2 = \sigma$) was accepted. Hence, a pooled t-test for difference in mean grades of the two populations (i.e., $\mu_1 - \mu_2$) was performed using the pooled estimator of population variance (σ^2) expressed as [10].

$$S_p^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} \tag{1}$$

Statistical Parameter	*Comparison group* Section 1 (non-BTS)	*Experimental* Group Section 2 (BTS)
Class Size, n	29	29
Mean, $\overline{X}$	3.034	2.621
Standard Deviation, S	0.823	0.677
F-Statistic	1.478	
F-Critical (two-tailed test)	1.882	
Pooled Estimator of Variance, S_p^2	0.568	
95% Confidence Interval on the Difference in Means	0.018–0.810	
t-Statistic	2.091	
t-Critical (two-tailed test)	2.003	

Table 2. Statistical Comparison of Prerequisite Knowledge in the Two Student Groups.

where n_1 and n_2 represent the sample size (number of students) in groups 1 and 2. With the assumption that the two populations are normally distributed, the resulting test statistic given as

$$t_0 = \frac{\overline{X}_1 - \overline{X}_2 - (\mu_1 - \mu_2)}{S_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \tag{2}$$

has a t distribution with degrees of freedom equal to $n_1 + n_2 - 2$. The confidence interval on the difference in population mean grades is given as

$$\begin{aligned} &\overline{X}_1 - \overline{X}_2 - t_{\alpha/2,n_1+n_2-2}\left(S_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}\right) \le \mu_1 - \mu_2 \le \\ &\overline{X}_1 - \overline{X}_2 + t_{\alpha/2,n_1+n_2-2}\left(S_p\sqrt{\frac{B}{n_1} + \frac{1}{n_2}}\right) \end{aligned} \tag{3}$$

For the null hypothesis H_0: $\mu_1 - \mu_2 = 0$ and $t_{0.025,56}$, the 95% confidence interval is found to be $0.018 \le \mu_1 - \mu_2 \le 0.081$. Since the confidence interval does not include zero, the null hypothesis is rejected with the conclusion that there is a statistical difference between the two groups. With the difference in mind, a decision was made to treat the students in Section 1 as the comparison group and those in Section 2 as the experimental group. Neither class had any prior knowledge of the experiential learning activity that was to be introduced midway during the semester.

IV. STUDENT ACTIVITIES

Although only the students in Section 2 had the benefit of using the BTS, both sections were given the same sets of assignments (12 total). Two of the assignments (henceforth called projects

A and B) were designed to also help assess the effectiveness of interaction with the BTS. All students were required to submit individual project reports, which were graded in a similar fashion.

Projects A and B, each containing a single beam bending problem, were given three weeks apart during the semester with students having a two-week period to complete each project. Even though project A was mainly concerned with a beam bending analysis and project B with a simple whiffletree design, they both shared the same basic activities as noted in Table 3. For each project, the students from both sections were divided into small groups, each given a different type of material and loading condition specified in the beam problem. Although the students in Section 1 were not required to use the BTS, they were also divided into small groups to encourage team effort in the completion of the projects. Typically, the students from Section 2 performed the experimental portion of the two projects in groups of two. Each student was required to submit a separate project report. The grades on projects A and B were added together and treated as one test grade for each student.

For the BTS group (Section 2), the experiments required taking measurements of normal strains and lateral deflections of the instrumented beams at the designated locations. The experimental procedure involved correct positioning of the test beam, applying the required boundary conditions, taking strain and deflection data at selected locations, making all necessary electrical connections, calibrating all strain and deflection gages, loading the beam incrementally, and recording the beam responses at each load level. Although the use of computational tools was not required, it was strongly encouraged, and for many of the students, it was a first engineering experience with Mathcad [11] or EXCEL [12]. Students used the measured strains together with the Young's modulus of the material to obtain the experimental value of normal stress at each strain gage location. Using the mechanics of material approach, students also calculated the beam deflection and normal stresses at the designated locations. Additionally, by determining the equation for the elastic curve,

1. Determine the support reactions.
2. Draw the shear and bending moment diagrams and identify locations of maximum shear and moment.
3. Determine the location of neutral axis.
4. Calculate the pertinent area moment of inertia.
5. Obtain Young's modulus by consulting material property tables and cite the reference.
6. Calculate the normal stresses and the corresponding strains at designated beam stations and locations on the cross-section.
7. Obtain the equation for the elastic curve and the deflection at the specified location.
8. Present all data in tabular and graphical form.
9. Submit your report in the specified format.

Table 3. Beam Analysis and Design Activties.

students were able to predict the lateral deflection at discrete points along the beam. While discussing the overall activity, each project report also contained a section devoted to the discussion of results and comparison of the predicted and measured responses.

Project A: Simply-Supported Beam with a Concentrated Force

For the beam and loading condition shown in Figure 3, the stresses and deflections at the indicated locations are to be determined. The beam cross section is rectangular with w = 3 in. and t = 0.25 in. The magnitude of load P is varied from 5 to 25-lb in 5-lb increments while its location *a* is kept fixed as indicated in Table 4.

To measure the impact of material properties on beam response, two different materials were considered. Each student group was assigned a separate beam specimen. Table 4 gives the listing of the beam specimens and the selected locations for load application *a* with the location of the deflection gage *D* at *d* = 18 in. Strain gages were attached on the top surface at three locations shown in Figure 3 as SG1, SG2, and SG3 at 5-in, 25-in, and 45-in distance, respectively, from the left support.

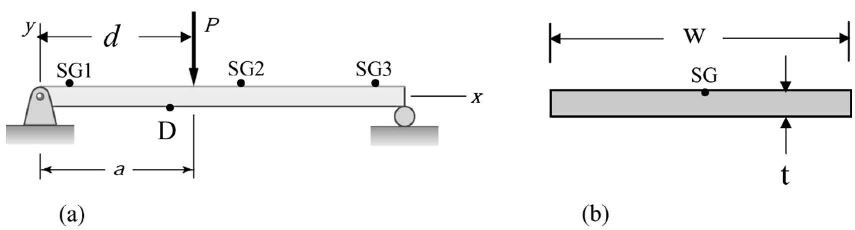


Figure 3. (a) simply-supported beam with a concentrated load and (b) rectangular cross-section.

Group	Material	a, in.
1	AA6061-T6	12
2	AA6061-T6	15
3	Steel 1018	12
4	Steel 1018	15
5	Steel 1018	20

Table 4. Beam Specimens and Load Positions for Project A.

Project B: Design of a whiffletree system for simulating a load distribution

The main objective of project B was to design a whiffletree system to relate a distributed loading condition to a single equivalent concentrated force of specific magnitude and location. The in-class lecture given to both sections regarding the whiffletree design demonstrated how a distributed load can be simulated in the laboratory. It was also shown that the accuracy of the simulation increases as the number of levels in the whiffletree is increased. An important feature of the lecture was to show that the internal bending moment due to the distributed load is not identical to that produced by a statically equivalent but discretely applied force system. It was left to the BTS group to recognize this important point when discussing the mismatch between the analytical results (strains and

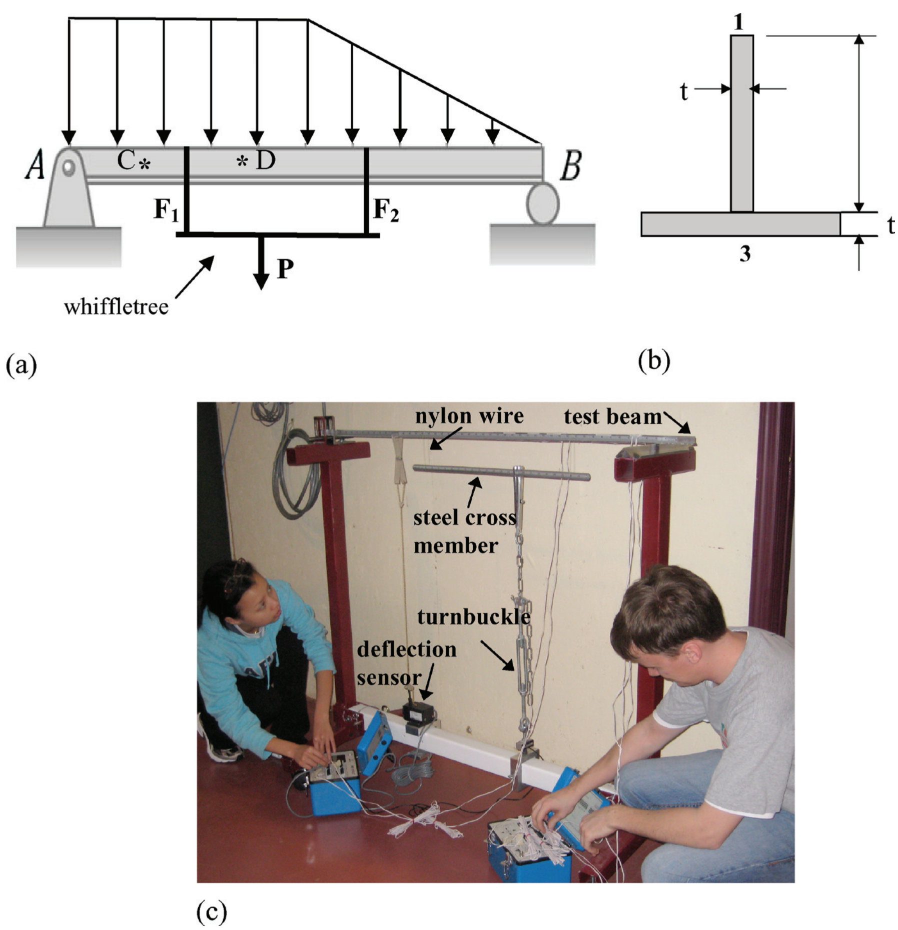


Figure 4. (a) simply-supported beam under a distributed load simulated by a simple whiffletree system (b) beam cross-section (c) whiffletree test in progress.

deflections) and the measured quantities. For this project, a two-level whiffletree was considered to simulate a load distribution. Figure 4 shows a simply-supported T-beam subjected to a uniform load over one-half its length and a triangular load distribution over the remaining half.

For whiffletree modeling, the distributed load was divided into two parts while locating the resultant force at the centroid of each part and finding the centroid of the overall distribution corresponding to the force resultant. Stations C at 10-in and D at 22-in in Figure 4a depict the locations of the uniaxial strain gages which are placed at positions 1, 2, and 3 at Station C and at 1 and 3 at Station D, as shown in Figure 4b.

The students in each section were divided into four groups with each group considering a different load-intensity as noted in Table 5. While the students from both sections were required to design the whiffletree for their loading level and complete the activities noted in Table 3, those in Section 2 were required to set up a similar whiffletree arrangement as shown in Figure 4c. High strength nylon wire was used to transmit the axial forces F1 and F2 (Figs. 4a and 4c) and a turnbuckle was used to apply the load P. A lightweight steel pipe was used for the cross-member. Prior to testing, students had to determine the location of the whiffletree members and know the value of the applied force P in order to produce their assigned distributed load. Precise measurements of strain gage locations, deflection gage location, and the cross-sectional dimensions of the beam had to be taken for comparison with the analytical solution.

V. ASSESSMENT OF LEARNING AND STUDENTS' PERCEPTIONS

Open feedback on project A, average scores on a final-exam problem, and responses to an anonymous survey were used for formative assessment of the two projects and for measuring the effectiveness of this experiential learning activity and its influence on students' attitudes toward mechanics of materials. Feedback was sought from the students in Section 2 (on a voluntary basis) as part of the report on project A to address outstanding issues prior to the implementation of the design problem in project B. Table 6 lists some of the comments from students regarding the experiential activity in conjunction with project A. The responses indicate that the majority of the

Group	Beam Length, ft	w_o, lb/ft
1	4	1.35
2	4	1.50
3	4	2.00
4	4	2.50

Table 5. Beam Specimens and Loading Conditions for Project B.

1. "…good example of how things are done in a lab."
2. "…worthwhile to calculate the values mathematically and see how closely they relate to the actual values found experimentally."
3. rewarding exercise
4. "…forced me to sit down and think about how each equation could be obtained for each part."
5. "…time consuming…"
6. "…helped to study for test."
7. "great project – provided real-world experience with the theoretical concepts covered in class."
8. "The best part was actually gaining insight on an actual test instead of only working equations on a sheet of paper."
9. "This exercise was very in depth."
10. "I never would have had such a great understanding of the material if I had never done this lab."
11. "Not only did the lab help me understand the material, it also forced me to learn how to use Mathcad and EXCEL programs. I used to hate these programs, but now I have realized how much they can help and how relatively easy they are to use."
12. "This was a tedious exercise, but it actually helped me on the test."
13. "I did not realize how time consuming the activity would be."
14. "After comparing the data, it was very surprising to see how accurate the strain values were."
15. "Personally, this experiment was extremely helpful for me. I am a very visual learner and this allowed me to actually see the principles and techniques that are taught in class."

Table 6. Sample of Feedback from Students in Section 2 after Completion of Project A.

Statistical Parameter	Comparison group Section 1 (non-BTS)	Experimental Group Section 2 (BTS)
Class Size	27	29
Mean	49	59
Standard Deviation	33.5	26.3
F-Statistic	1.627	
F-Critical (two-tailed test)	1.897	
Pooled Estimator of Variance, S_p^2	897.2	
95% Confidence Interval on the Difference in Means	−26.03−6.10	
t-Statistic	−1.233	
t-Critical (two-tailed test)	2.010	

Table 7. Statistical Comparison of Student Groups' Performance on the Final Exam—Whiffletree Problem.

students found the beam experiments to be helpful both in terms of providing a hands-on activity as well as improving their understanding of key concepts.

On the final exam, a problem concerning the analysis of a whiffletree system was posed to assess the difference in comprehension levels and analysis skills of the two sections. Table 7 gives the performance characteristics of the two groups with regards to the whiffletree problem. Class size in the Comparison group dropped to 27 as two students did not take the final exam. Comparison of the overall mean scores of the two groups reveals a higher average for the experimental group. As in the case of prerequisite knowledge comparison, here also a two-tailed F-test was done, which showed no difference in the standard deviations of the two populations. Using the pooled t-test for difference in mean grades of the two populations resulted in the confidence interval of $-26.03 \leq \mu_1 - \mu_2 \leq 6.10$. Since the confidence interval includes zero, we cannot conclude that there is a statistically significant difference in the means.

At the end of the semester, students in both sections responded to an anonymous survey that helped to assess their attitudes toward mechanics of materials, in general, and projects A and B, in particular. A sampling of the survey responses is shown in Figures 5–7, with those from Section 2 (the experimental group) identified as BTS and Section 1 (comparison group) as No BTS. Figure 5 shows the students' self assessment with regard to key engineering mechanics concepts. For each survey question, the mean, standard deviation and the 95% confidence interval of each response are also shown. The responses from both sections indicate that the majority of the students gained a deeper comprehension with regard to key concepts. Additionally, the students felt that their skills for both analysis and design were improved. The experiential activity, assessed by the BTS group is shown in Figure 6. As can be seen, majority of the class felt that the hands-on activity gave them

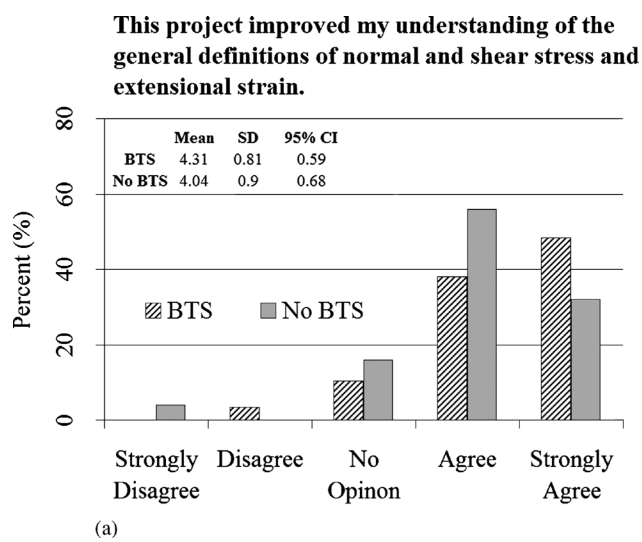


Figure 5. Student self-assessment responses regarding engineering mechanics concepts for (a) increased understanding of strain, (b) increasing ability to analyze and design structural members, (c) increased ability to analyze structural members and (d) increased ability to analyze the stress and strain distribution. (Continues)

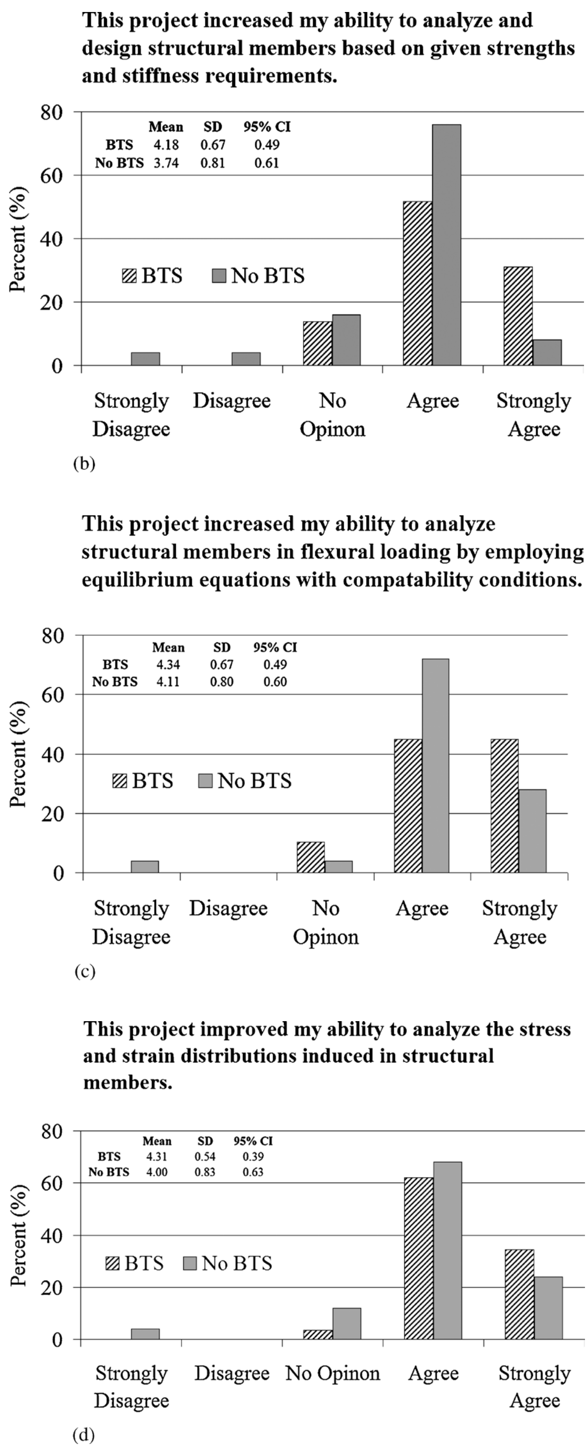
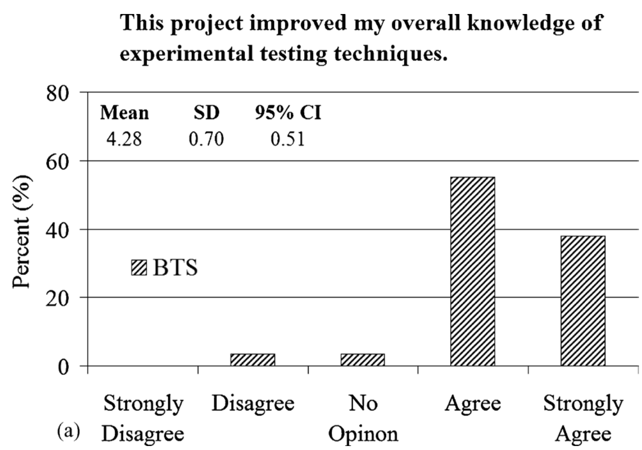


Figure 5. (Continued ...)

insight into real-world issues regarding experimental testing and they expressed "strong agreement" with it being a positive learning activity. Figure 7 shows the responses from both sections regarding the overall value of the two projects. Again the responses indicate that the majority in both classes considered the projects a worthy endeavor advocating their continuation, with the BTS group having a stronger opinion about the benefits of the projects.



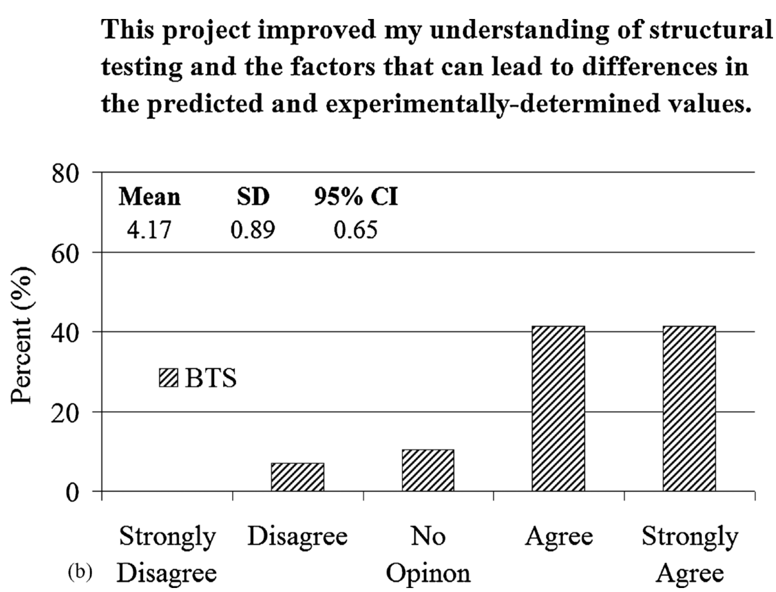


Figure 6. BTS activity evaluation (a) improvement in overall knowledge of experimental testing (b) improvement in understanding of structural testing (c) good experiential learning activity.(Continues)

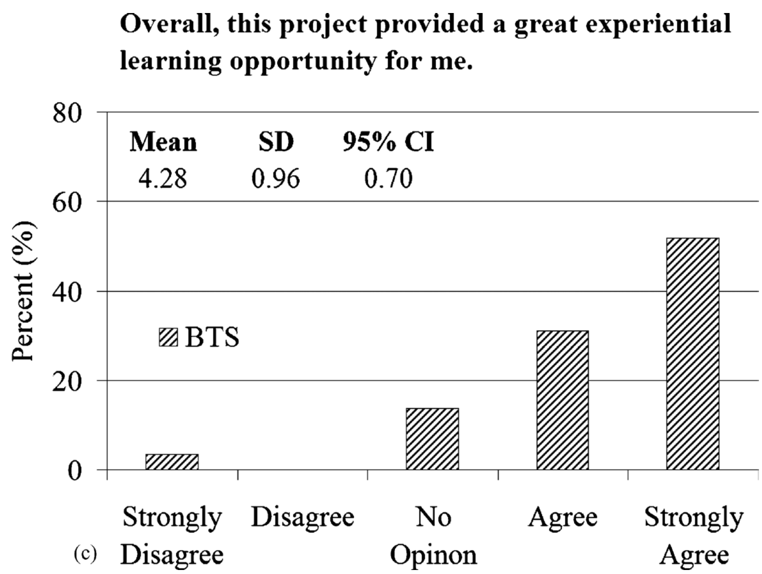
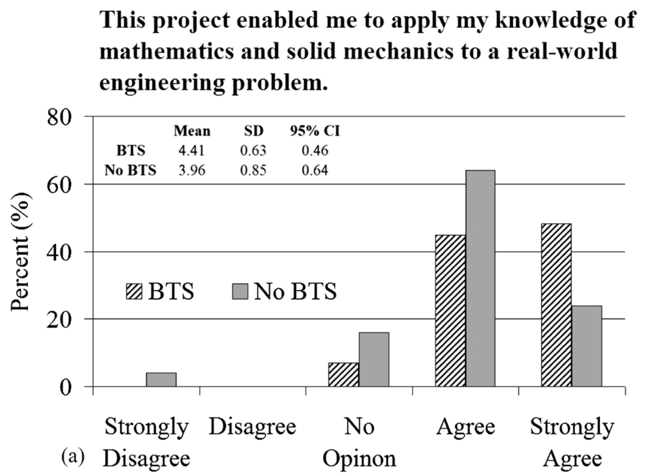


Figure 6. (Continued …)

In addition to the survey questions, general comments were also encouraged and a sampling is shown in Table 8. Some of the written comments from Section 1 (No BTS) indicate that they missed the hands-on experience. Both classes endorsed continuation of the projects and regarded them as being an overall positive learning experience.

This activity has also been a learning experience for the first author with much insight gained into subtle areas that lead to student confusion. Basic concepts, such as the axis about which the moment of inertia is computed, proper interpretation and implementation of support conditions, etc. were clarified for the BTS group. Despite the in-depth lecture regarding the whiffletree design and the fact that the distributed loading and its statically equivalent force system do not produce identical internal bending moments, the majority of the BTS students failed to use this point to explain the discrepancy between their analytical and measured results (strain and deflection). The most common complaint was that the exercises were very time consuming. The actual test implementation and data acquisition typically took thirty minutes, but the two reports took much longer than the students had expected. In the future, the hands-on exercise will be required for the design project only and more emphasis will be given to the final report. Oral presentation by each team may also be incorporated, thereby giving students an opportunity to compare not only results but also provide an atmosphere for exchange of ideas. Additionally, due to the versatility and portability of the BTS, plans are underway to incorporate use of the system for demonstrating key principles to complement in-class lectures.



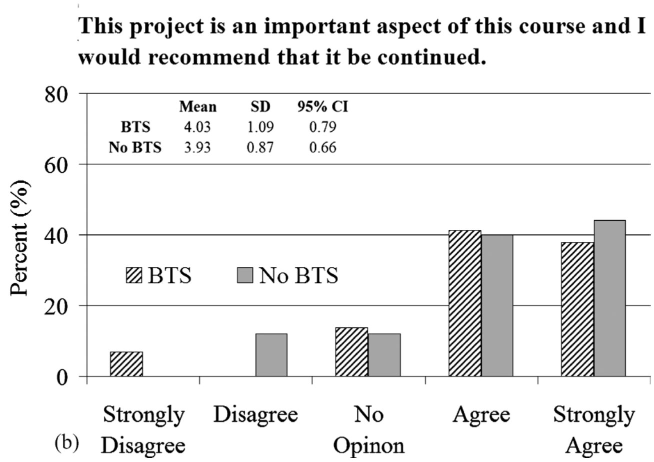


Figure 7. Project evaluation from both classes: (a) application to real-world problem; (b) continuation of project recommended.

VI. CONCLUSIONS

The design and application of a beam testing system (BTS) as a means of experiential learning in the mechanics of materials course were discussed. Using the analysis of the prerequisite knowledge of the classes as a reference, the effectiveness and impact of combining engineering analysis with physical experiments were measured using student surveys as well as student performance on a common final exam problem. The collected responses indicated that students valued the hands-on activity and they were generally positive on the coupling of engineering analysis with experiments. The statistical analysis revealed that the comparison group had a higher average than the experimental group with regards to prerequisite knowledge, but the statistical analysis of the grades from the common exam

BTS	"I learned more than I have about mechanics of materials with the project than without it." "These two projects were very time consuming, but I enjoyed the projects and it helped my grade" "I was very happy that the problems we were given modeled everything we had been doing in class." "The project allowed me to have a "hands on" experience with the course material. This was very beneficial to me because I learn better when I can actually touch and see what I am analyzing." "I very much enjoyed the project and would highly recommend it be continued."
No BTS	"I think it might have been beneficial to see how the loadings would actually affect the beam experimentally." "After looking at the projects that the other section did, I hope that in the future that both sections can do theirs… it seemed more practical…" "I enjoyed the project. It gave me a better understanding of the problem and the formulas that I was using. It think it should be continued. "I think all class sections should have the opportunity to use the hands-on problems." "Lengthy, very involved, overall an excellent project."

Table 8. Sample of Students' Comments From Anonymous Survey.

problem indicated that the students in the comparison group performed as well as the students in the experimental group, although the experimental group average was 20% higher than that of the comparison group. From the instructor's point of view, the integration of an experiential activity in an otherwise lecture-only course is a positive change, although it tends to consume additional time.

After reviewing the responses from the students and considering report and test scores, it is concluded that, in the future, only the design problem will be assigned as the experiential activity, and one report regarding this exercise will be required. Additionally, the BTS will be used as a demonstrative tool in future classes, where various concepts, such as the difference between a simply supported condition and a fixed support, can easily be demonstrated and other simple experiments can be quickly incorporated in the lecture-based course. Although additional assessment is needed to fully quantify the effectiveness of this experiential activity, the feedback from the students reveals a preference for hands-on engagement incorporated into the traditional analysis course. The incorporation of the BTS into the mechanics of materials course allowed for a design element to be introduced into a traditional analysis course, thereby increasing students' real-world knowledge.

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REFERENCES

[1] Vander Schaaf, R. and Klosky, J.L., "Classroom Demonstrations in Introductory Mechanics," *Journal of Professional Issues in Engineering Education and Practice*, Vol. 131, No. 2, 2005, pp. 83–89.

[2] Vander Schaaf, R. and Klosky, J.L., "Show Me the Money! Using Physical Models to Excite Student Interest in Mechanics," Proceedings of the 2003 American Society for Engineering Education Annual Conference and Exposition, Nashville, TN, June 22–25, 2003. http://soa.asee.org/paper/conference/paper-view.cfm?id=18920.

[3] Schmucker, D.G., "Models, Models, Models: The Use of Physical Models to Enhance the Structural Engineering Experience," Proceedings of the 1998 American Society for Engineering Education Annual Conference and Exposition, Seattle, WA, June 28–July 1, 1998. http://soa.asee.org/paper/conference/paper-view.cfm?id=13901

[4] Kresta, S.M., "Hands-on Demonstrations: An Alternative to Full Scale Lab Experiments," *Journal of Engineering Education*, Vol. 87, No. 1, 1998, pp.7–9. http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=131.pdf

[5] Meyer, K.F., Ressler, S.J.,and Lenox, T.A., "Visualizing Structural Behavior: Using Physical Models in Structural Engineering Education," Proceedings of the 1996 American Society for Engineering Education Annual Conference and Exposition, Washington, DC, June 23–26, 1996. http://soa.asee.org/paper/conference/paper-view.cfm?id=13007

[6] Crone, W., "Using an Advanced Mechanics of Materials Design Project to Enhance Learning in an Introductory Mechanics of Materials Course," Proceedings of the 2002 American Society for Engineering Education Annual Conference and Exposition, Montreal, CA, June 16–19, 2002. http://soa.asee.org/paper/conference/paper-view.cfm?id=16668

[7] O'Neill, R., Geiger, R.C., Csavina, K., "Making Statics Dynamic! Combining Lecture and Laboratory Into An Interdisciplinary, Problem-Based, Active Learning Environment," American Society for Engineering Education Annual Conference and Exposition, 2007, Honolulu, HI, June 24–27, 2007. http://soa.asee.org/paper/conference/paper-view.cfm?id=5089

[8] Sepahpour, B., "Design Of An Affordable Model Laboratory For Mechanical And Civil Engineering Programs," Proceedings of the 2003 American Society for Engineering Education Annual Conference and Exposition, Nashville, TN, June 22–25, 2003. http://soa.asee.org/paper/conference/paper-view.cfm?id=18187

[9] Campbell, M., *"Oh Now I get It!," Journal of Engineering Education,* Vol 88, No. 4, Oct. 1999. http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=659.pdf

[10] Montgomery, D.C. and Runger, G.C., Applied Statistics and Probability for Engineers, 2nd Ed., Wiley, New York, 1999, pp. 375–429.

[11] Mathcad, V. 14.0, Parametrics Technology Corporation, 2007. http://www.ptc.com/appserver/mkt/products/home.jsp?k=3901

[12] EXCEL, 2007, Microsoft Office. http://office.microsoft.com/en-us/excel/default.aspx

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