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Creativity and the Undergraduate Laboratory Experience

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An important aspect of laboratory instruction is the encouragement of creative approaches to solving engineering problems. The undergraduate laboratory experience is a sterile repetition of canned experiments which neither challenge the student intellectually nor encourage creativity. To address this deficiency at the University of Oklahoma, we have restructured the undergraduate curriculum to incorporate challenging, open-ended problems of an experimental nature. In this paper, our experience with this approach to undergraduate laboratory instruction will be described. Particular attention will be devoted to the issue of the necessity of student exposure to basic laboratory skills prior to taking the advanced-level problem-solving course. The specific changes needed in the curriculum will be presented along with a discussion of resource requirements (equipment, materials, supplies, time, etc.) for a successful program.

EDUCATIONAL SUMMARY

1. The paper describes new training tools or laboratory concepts/instrumentation/experiments in mechanical engineering laboratory courses.
2. Junior and senior level students are involved in the use of equipment.
3. New aspects include integration of equipment into open-ended problems to be solved by measurement and or experiment.
4. The incorporation of the material in engineering teaching is described in the paper.
5. No further texts or other documentation accompany the presented materials.
6. The concepts presented have been tested in three different semesters and have proven to be correct.
7. Other comments: modern equipment that can be applied to a variety of measurement problems is needed to enhance the laboratory education of engineering students.

INTRODUCTION

IN THE School of Aerospace and Mechanical Engineering, at the University of Oklahoma we have recently completed a restructuring of the undergraduate, experimental course sequence. Prior to these changes, undergraduates were required to take a seven-credit-hour laboratory sequence consisting of: (i) A general three-credit-hour course on measurement and experimentation; and (ii) Two two-credit-hours courses of a specialized nature selected from several lab courses offered, e.g. Experimental Stress Analysis Laboratory (described in the next section), Propulsion Laboratory, Non-Destructive Testing Laboratory, Fluid and Thermal Science Laboratory, and Dynamics Laboratory. While this sequence of courses was meeting some of its principal goals in exposing the students to a wide range of instruments and experiments, we found the basic sequence to be restricted in several key respects. Most of the experiments performed were of a prepackaged nature with clearly defined expectations for the results. There was a great deal of redundancy in the course material. And finally, due to equipment limitations, the level of sophistication of the experiments was quite limited.

Accordingly, we decided on a basic change in philosophy. By expanding the introductory level course from one 3 hr course to two 2 hr courses (one for dynamics and solid mechanics and the other for fluid mechanics and thermal sciences) and insisting that all instructors adhere closely to a formal syllabus, we could ensure that all incoming students into the specialized courses would have been exposed to fundamentals: design ofexperiments, statistical analysis, digital data acquisition, signal processing, etc. With this common knowledge base, we could eliminate redundancy in the curriculum. The specialized courses could then be redesigned to eliminate much of the dull, repetitive work associated with canned experiments. Finally, we applied and received an NSF ILI grant for the experimental mechanics course. In the past, specialized equipment (purchased for research grants) could be made available to students on a limited basis. The ILI grant allowed us to obtain several critical instruments which could be devoted full time to undergraduate education. The final result, in our opinion, was a vastly improved laboratory instruction program.

In this paper, we will restrict our attention to the Experimental Stress Analysis course, as the ILI grant was specifically requested for this course. However, it should be emphasized that the changes made would not have been possible without a complete restructuring of the entire experimental curriculum. A basic introductory course with clearly defined objectives was required before any changes could be made in any of the advanced level courses. Furthermore, the changes in this course are representative. Similar changes have been made to all of the advanced level courses.

EXPERIMENTAL STRESS ANALYSIS (BEFORE)

Prior to implementation of these changes, Experimental Stress Analysis was a standard, laboratory course at the University of Oklahoma with one contact hour in lecture and two contact hours in the laboratory. *Experimental Stress Analysis*, authored by Dally and Riley, was the text used in the course. The basic material covered in the semester included a review of stress and strain analysis, an overview of strain-measuring devices, strain gage design, strain gage circuits, rosette analysis, photoelasticity, holography and constitutive modeling. A variety of canned experiments were performed by the students including:

- Elastic modulus determination—a tensile specimen was instrumented with a rosette and tested to failure. Students were asked to determine E, p and analyze the limitations of linear elasticity theory.
- Biaxial strain measurement—a cylindrical pressure vessel with hemispherical caps was instrumented with strain gage rosettes at several locations. Readings were taken at several different pressure levels and compared with theory.
- Thermal strain measurement—a test specimen of dissimilar materials was prepared and instrumented with strain gages. The specimen was placed in an oven and heated. The students analyzed the results in light of the thermal expansion differences between the two media.
- Constitutive modeling—students tested polymer specimens at varying strain rates to determine the validity of the Maxwell and Voigt models of material behavior.
- Photoelastity—two birefringent test specimens were prepared, one notched and one unnotched. Using a polariscope with a load frame and the results from the unnotched specimen as calibration, students were required to determine stress concentration factor for the notch.

Several of these experiments were moved into the introductory measurement and experimentation course. Since many of these ideas are also presented in the solid mechanics course taken concurrently by many students, there is an added benefit gained through reintroducing basic concepts in the lab course. Ideally, we feel that simultaneous enrolment in the two courses should be required for maximum pedagogical benefit.

EXPERIMENTAL STRESS ANALYSIS (AFTER)

In the fall 1991 semester, the character of the Experimental Stress Analysis course was changed from a traditional approach to a course which emphasized the development of open-ended problem-solving techniques to experimental problems instead of lectures coupled with packaged laboratory exercises. In this way, we hoped to stimulate the creative process by encouraging students to explore various alternative solutions to a problem without an expected single solution rather than perfunctory performance of instructions for a canned experiment.

One of the major difficulties in developing the course was the selection of problems which were interesting and intellectually challenging yet within the capabilities of undergraduate students, given the equipment, budget and time constraints. We sought instrumentation which would give the students the flexibility to handle a variety of potential problems. The core of the equipment grant was a high-speed laboratory microcomputer (486/25). Since many of the experiments that we envisioned when we wrote the original proposal involved the analysis of photographic data, we requested a frame grabber and image analysis software for detailed analysis of the digitized images. This was supplemented with a cabinet X-ray and an ultrasonic data acquisition system for materials characterization. This equipment was supplemented (on an as-needed basis) with research equipment in the department. We also required each student to pay a supplemental \$50.00 laboratory fee which provided a budget for the purchase of many of the material supplies and small items required for several of the projects. This budget was adequate for a class of 20 students broken down into five groups of four student researchers.

At the start of the semester, the student groups met with the instructor to discuss the nature of the course and possible research topics were suggested. The student groups were also encouraged to develop projects of their own design which fit into the basic objectives of the course. Only one of the groups (composite baseball bat) chose to work on their own projects. The projects addressed in the first offering of this course were:

- Composite microstructure—in this project students were asked to develop an automated method of determining the precise layup sequence in fiber reinforced composites. This would be achieved through analysis of the digitized photomicrographs of composite cross-sections.
- Epstein layer sample—this group was charged with responsibility for the manufacture and testing of a sample with continuously varying

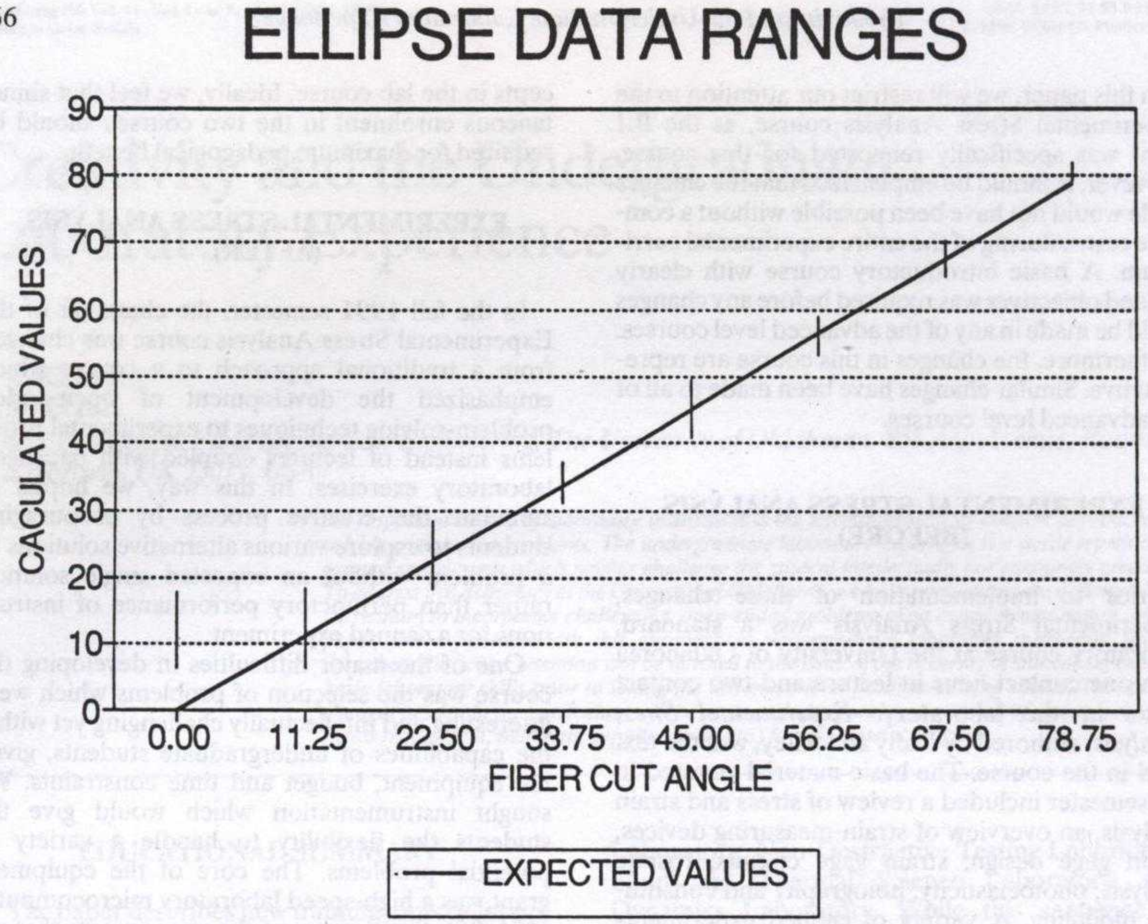

Fig. 1. Values of the Fiber Angle Calculated from Image of the Cut Surface

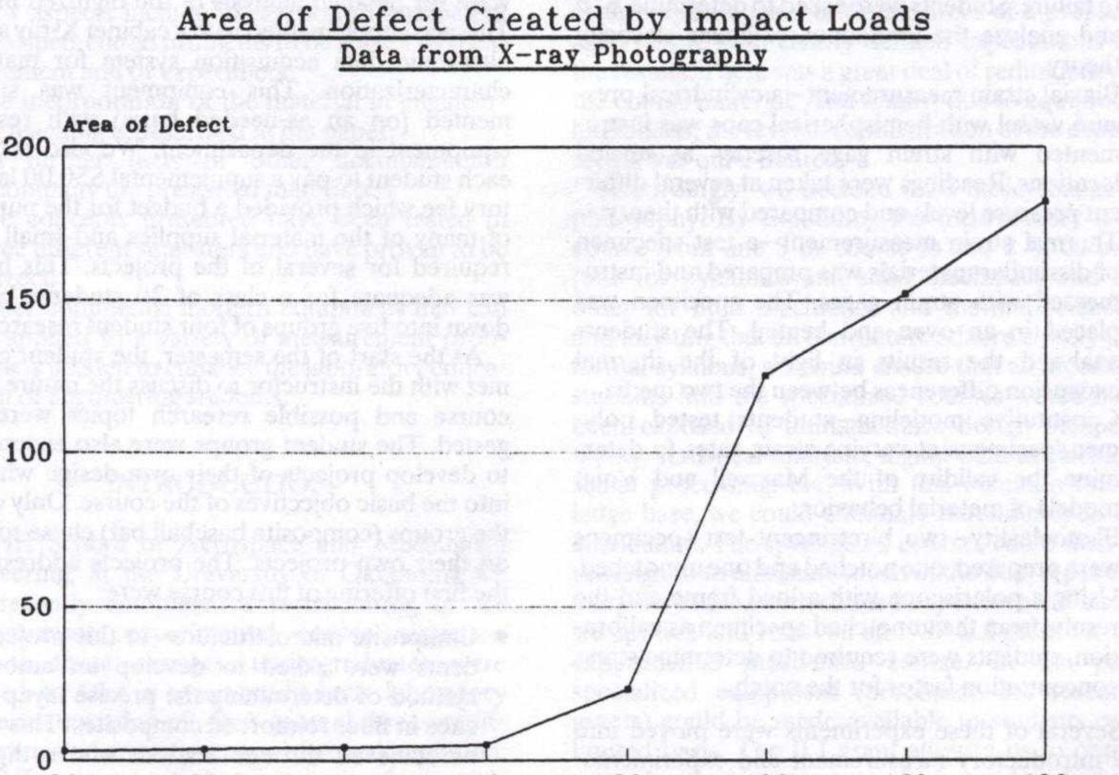

Fig. 2. Comparison of Impact-Damaged Regions Measured by (a) X-ray and (b) Thermography

material properties in one direction, a so called Epstein layer.
- Two-dimensional strain analysis—in this project the goal was the development of an experimental technique which could be used to characterize large deformations (typical of biological soft tissue) in a full two-dimensional field.
- Composite baseball bat—this group was interested in the performance of composite baseball bats relative to conventional wood or aluminum bats. Here, we decided to focus on the development of experimental techniques to track damage development using modal analysis.

RESULTS

By the end of the semester, all groups had made good progress toward their goals with the results from some of the groups exceeding the instructor's expectations. The accomplishments were as follows:

Composite microstructure

This group was able to develop a computer algorithm to identify automatically the orientation of a given ply from the ratio of the major and minor axes of the fiber image (i.e. a fiber cut at 0° is imaged as a circle, a fiber cut at 45° is imaged as an ellipse, etc.) with the major axis/minor axis ratio increasing with increasing angle according to a cos θ relationship. Figure 1 shows the results obtained along with error bars showing experimental variability. Good agreement was found for all angles except 0°. This result was not unexpected since sensitivity of the technique at 0° is a minimum.

Thermal imaging

Thermal images of composites subjected to varying degrees of impact damage were generated using a heat lamp source and a borrowed thermal imaging camera from an ongoing research project. Results were compared with X-rays of the damaged region enhanced with an opaque additive (Fig. 2). Good qualitative agreement between the estimated damage zone size between the two techniques was found.

Epstein layer sample

After several failures with a variety of approaches, this group finally developed a technique for introducing a controlled variation in

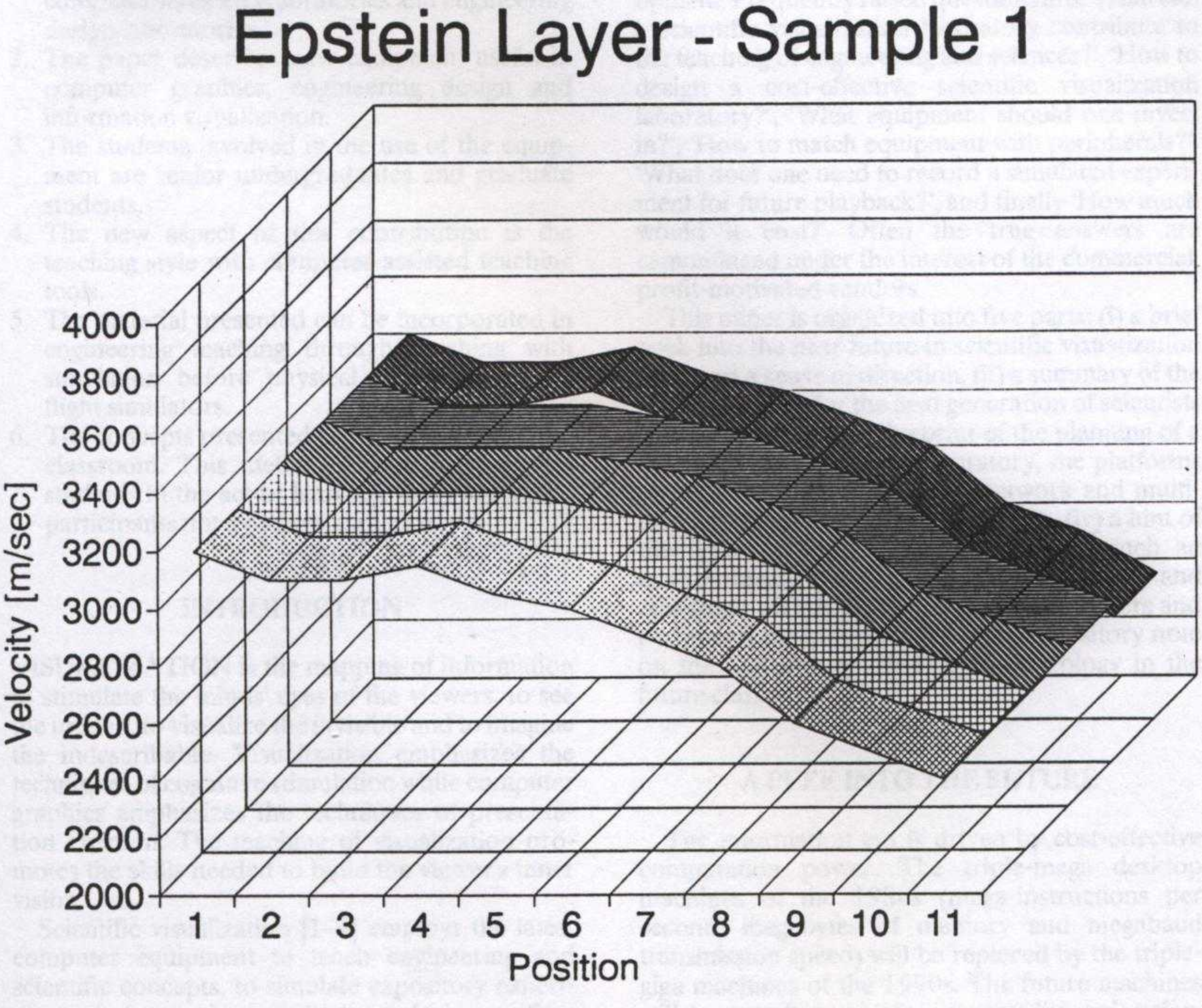

Fig. 3. Measured Ultrasonic Velocities in an Epstein Layer

material properties using a composite sample with an epoxy matrix and an aluminum filler. A 60 layer sample (overall dimensions 3 in. x 3 in.) was prepared with each layer having a different ratio of filler to matrix ranging from 0/100 at one end to 80/100 at the other. An illustration of the local property variation achieved is presented in Fig. 3 where longitudual velocity is presented as a function of position. A material property (velocity) difference of approximately 30% was achieved.

Composite baseball bat

For this group only partial results are available. A bat was obtained and instrumented with strain gages. A pitching machine was borrowed from the University's baseball team and the strain response was recorded with increasing number of impacts. To this point, no significant difference in modal response has been discovered. Testing is continuing to determine if modal analysis can be used to detect damage initiation and growth in the samples.

CONCLUSION

The restructuring of the undergraduate laboratory courses has infused enthusiasm in the students taking the courses and in the faculty responsible for the courses. The open-ended format of the projects allows the student to develop skills in designing experiments and in dealing with unplanned difficulties. The continued success of this approach will depend on the availability of contemporary laboratory equipment suitable for the relevant experiments.

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