AC 2011-710: INDIVIDUAL DATA ACQUISITION AND EXPERIMENTATION IN UNDERGRADUATE MECHANICAL ENGINEERING LABORATORIES

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Individual Data Acquisition and Experimentation in Undergraduate Mechanical Engineering Laboratories

Introduction

Undergraduate teaching laboratories in mechanical engineering curriculum are traditionally group-oriented courses with activities centered on large, singularly-purposed experimental apparatus. This is often caused by the cost and maintenance support of the experiments and not pedagogical reasons. Apart from reasons specific to large-scale laboratory experiences (hydraulic systems, HVAC systems, mechanical testing load frames), this work explores an alternative model of all individually-based data acquisition and experimentation activities in a mechanics-of-materials laboratory course. The main goal of the course was to expose *every* student to as much data acquisition and hardware/software/experiment interaction as possible while minimizing the cost required as much as possible.

The Course

The Mechanics-of-Materials Laboratory (MoM lab) curricular requirements are explicitly delineated as: experimental characterization of the mechanical properties of engineering materials, precision instruments design, computer-based data acquisition, statistical uncertainty analysis, and preparation of engineering reports. While not explicitly stated, the placement of the course in the mechanical engineering sequence also requires that the MoM lab serve as the de facto electrical circuits laboratory where hands-on experience with DC circuits is gained through circuit construction and measurement. Previous incarnations of this course had groups of students (3-5) performing experiments at various static stations in the laboratory. Group reports would be composed and submitted for grading. The week-to-week flow of activities was well established and varied little from term to term. In graduating-senior exit interviews the anecdotal feedback on the course was neutral: students did not dislike the course, but there was not a predominance of enthusiasm for the course which lacked beneficial and impactful hands-on experiences. This feedback motivated the present recreation of the MoM lab directly purposed to give every student as much practical experience as was feasible.

Methods and Approach

The key factor in maximizing individual student experiences was the provision of a low-cost universal serial bus data acquisition (USB DAQ) device to every student and interfaced with the student-owned laptop computers. The USB DAQ devices were distributed at the beginning of the semester and *not* collected at the conclusion of the course. The device purchases were financed through assessment of laboratory fees accompanying tuition, giving the students the impression that the devices were complimentary. The laptop computer ownership requirement was mandated by the mechanical engineering department and provided the computational foundation for all experiments. The software used to interface the USB DAQ device and computer was National Instruments LabVIEW™ provided to the students and financed through a university agreement with National Instruments. Every student walking into the laboratory brought with them the ability to acquire data from various transducers (USB DAQ), write software to acquire and process that data (LabVIEW), and a computer to store data and author reports.

Given these capabilities, it was necessary to construct laboratory experiences that were both scientifically non-trivial and individually accomplishable. Since the USB DAQ device had four channels of analog signal acquisition capability, transducer selection was based around low cost (12 seats per laboratory section), robustness (12 sections per week), and analog DC voltage output. Mechanics of materials oriented experiments were designed around these transducer types: linear variable differential transformers (LVDTs) for displacement measurement, conditioned and amplified strain gauges and load cells for strain and force, and thermocouples with converters for temperature.

Modular bench top experimental frames, shown in Fig.1, were conceived and fabricated for each experimental station. The frames were designed to receive different accessory components varying week-to-week depending on experimental topic. Each week would be a singular encapsulated experience. For example: one week would be full-bridge strain gauge load cell calibration and the following week would be as separate investigation of elastic modulus testing of metal wires via hanging masses and LVDT displacement measurements. The experimental activities would be changed out each week but with the thread of commonality being that the software programs written for the USB DAQ device from the previous week's activity were employable in subsequent activities. As a reference a single mechanical tensile-test load frame cost about $30,000 where all of the twelve modular experiment stations were designed and assembled for less than $25,000

The overwhelming majority of students coming into the laboratory course had no previous programming experience in LabVIEW. In order to minimize the impact of not knowing how to program in "G" (the LabVIEW programming language), a set of course software libraries were developed and distributed to the students that provided a functional framework through which the students could with minimal instruction be able to perform experiments almost immediately. A screenshot example of the distribute course framework code is shown in Fig. 2. The course software framework also provided for a common platform (a programming sandbox) that students could modify and improve to suit their individual experimental goals and desires. The course framework removed much of the programmatic minutiae involved with device communication and channel creation without isolating the students from it as inquisitive students could examine the source code to see how the more complicated code operated.

An example laboratory exercise is shown in Fig. 3. In this laboratory, students would acquire the analog voltage output of an LVDT that was connected to a vibrating stainless steel cantilever beam. The first-mode natural frequency of the beam is found experimentally from a discrete

Fourier transform analysis of the dynamically changing voltage signal. The effects on natural frequency of changing end mass and beam length were also explored. Additional laboratory exercises included: building a Wheatstone bridge with resistors and measuring the bridge voltages with the DAQ devices, calculating elastic modulus by stretching steel wires using masses and LVDT’s to measure length change, testing hardness using a force transducer and diamond-tipped indenter with controlled depth displacement.

Discussion

From an instructional perspective, the beneficial aspects to the individual experimental model were realized through observation of student participation and performance. In group laboratory settings it is easy for students to electively defer experimental responsibilities to the more motivated group members while still receiving a portion of the group grade. There are grading mechanisms by which to minimize this effect but total engagement of all students in group laboratory settings is difficult, if not impossible. Individual experiments (and later report writing) constrain the student to face any experimental apprehensions that may exist. Students are encouraged in the laboratory to focus on acquiring data which is often effective at focusing the reluctant students on the experimental task-at-hand. As the course progresses the evolution of the student as experimental researcher is evident to the astute observer for both extroverted and introverted laboratory student types.

After each laboratory session the students are required to compile, analyze, and discuss the pertinent results in individually submitted weekly reports. Depending on institutional course loading this can create a large volume of reports that need grading and assessment, requiring significant personnel resources. This issue was addressed through specific personnel strategy decisions. The course was assigned two dedicated graduate teaching assistant graders whose sole responsibility was to grade and provide feedback on the reports. The reports were submitted and graded electronically through the online course management system (Sakai). This helped in eliminating large stacks of reports being trafficked around campus by both students and graders, reducing waste, and increasing efficiency of report delivery and return.

Laboratory administration was performed by a dedicated instructor who was responsible for upkeep and maintenance of the individual stations, starting each laboratory section with a brief introduction, and development of new experiments for the bench top frame. Laboratory administration duties were supplemented by the employment of undergraduate assistants. These students were selected from the top-perfomers of previous semesters and offered the position of being purely experimental help for current students. The undergraduate assistants were given no grading permissions and were very motivated in rendering aid to fellow students. The use of undergraduate instructional assistants allowed for help present in the lab and was both instructionally expedient and economically optimal as undergraduate student pay is 3-5 times less than a full-time position. For the same dollar-for-dollar expenditure there was more available help in the laboratory throughout the week.

Student feedback and assessment of this approach was performed via anonymous student course evaluation surveys comparable to previous traditional group-experimentation laboratory courses where similar surveys were given. The results of the compiled evaluation surveys are shown in Fig 4. The student feedback is positive with skewed histogram distributions towards “excellent” and “above average” compared to the previous laboratory course models. The qualitative feedback on the surveys (free-form written comments) were also very positive with the most common comment pertaining to the enjoyment of the hands-on experiences which from an instructive standpoint is correlated back to simple, profound, individually-based activities. While it is recognized that group projects are not favored by students, the sharp contrast in student feedback data suggests a positive result above simply removing the group project requirement.

Conclusion

The introduction of the individual experiment model in the MoM lab was positively perceived from both a student and instructor perspective. Students were more intellectually stimulated and as a group were provided more hands-on experiences than in previous incarnations of the course. The individual experiment model requires a significant expenditure in terms of energy and time to get initiated, but once the curriculum is established the results of this paper suggest a cost-effective way of increasing engagement and impact in undergraduate mechanical engineering teaching laboratories.

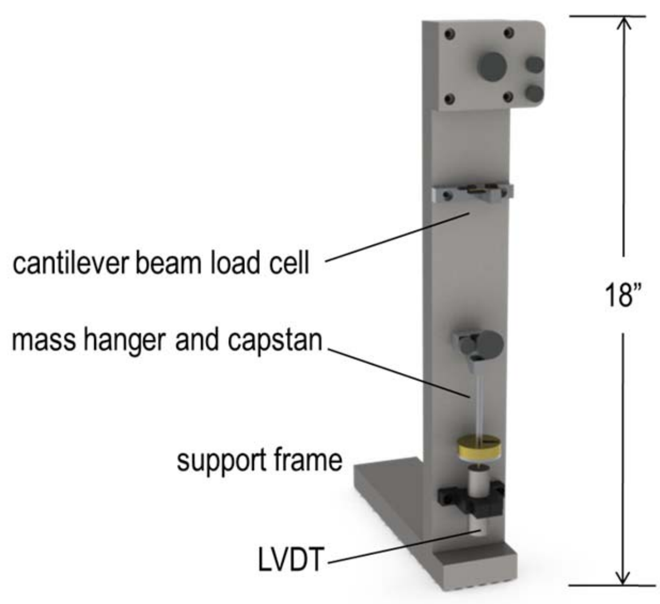

Figure 1. Bench top experimental station

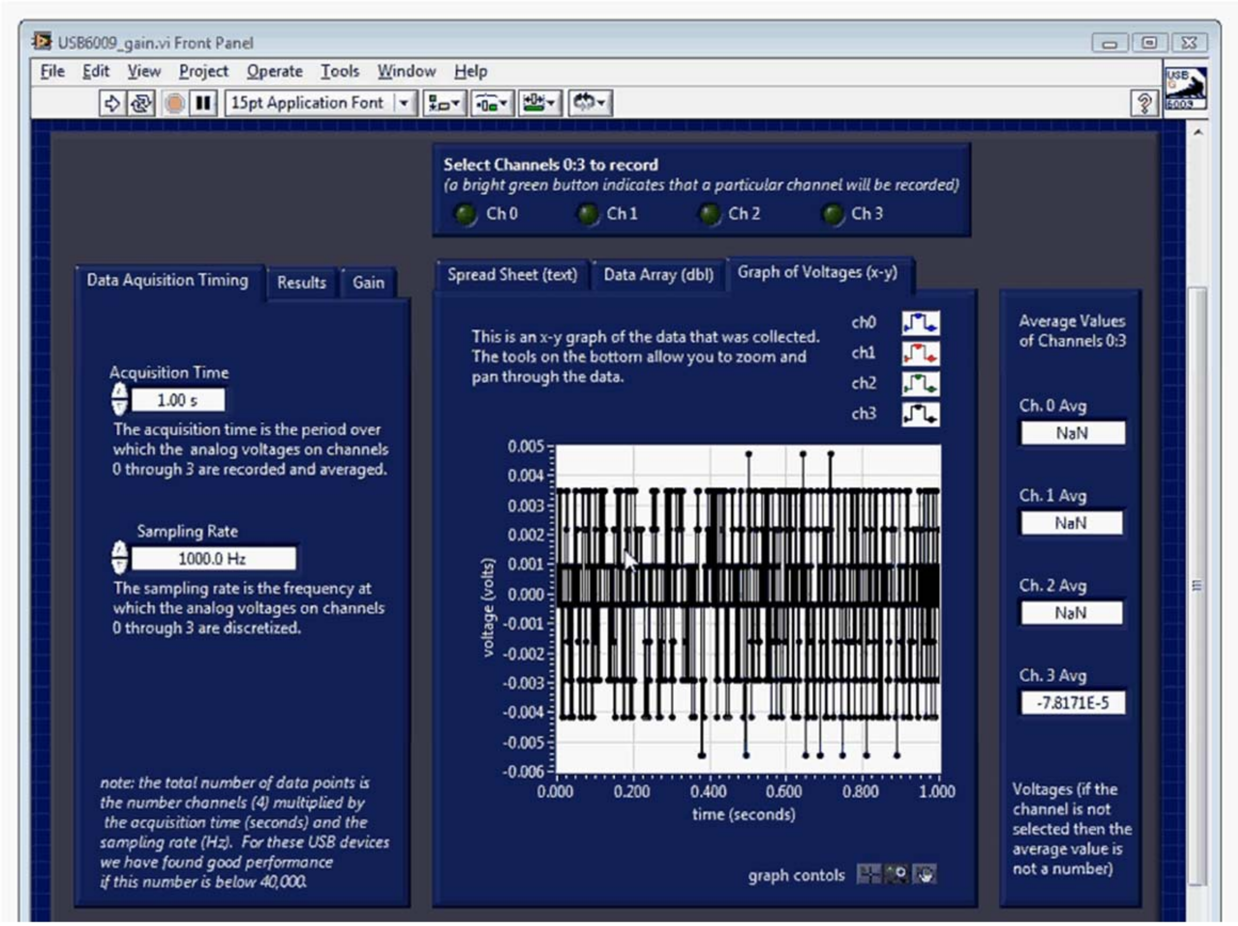

Figure 2. Screenshot of the LabVIEW course framework program front panel distributed to all students that enabled students to use their DAQ devices almost immediately to perform experiments

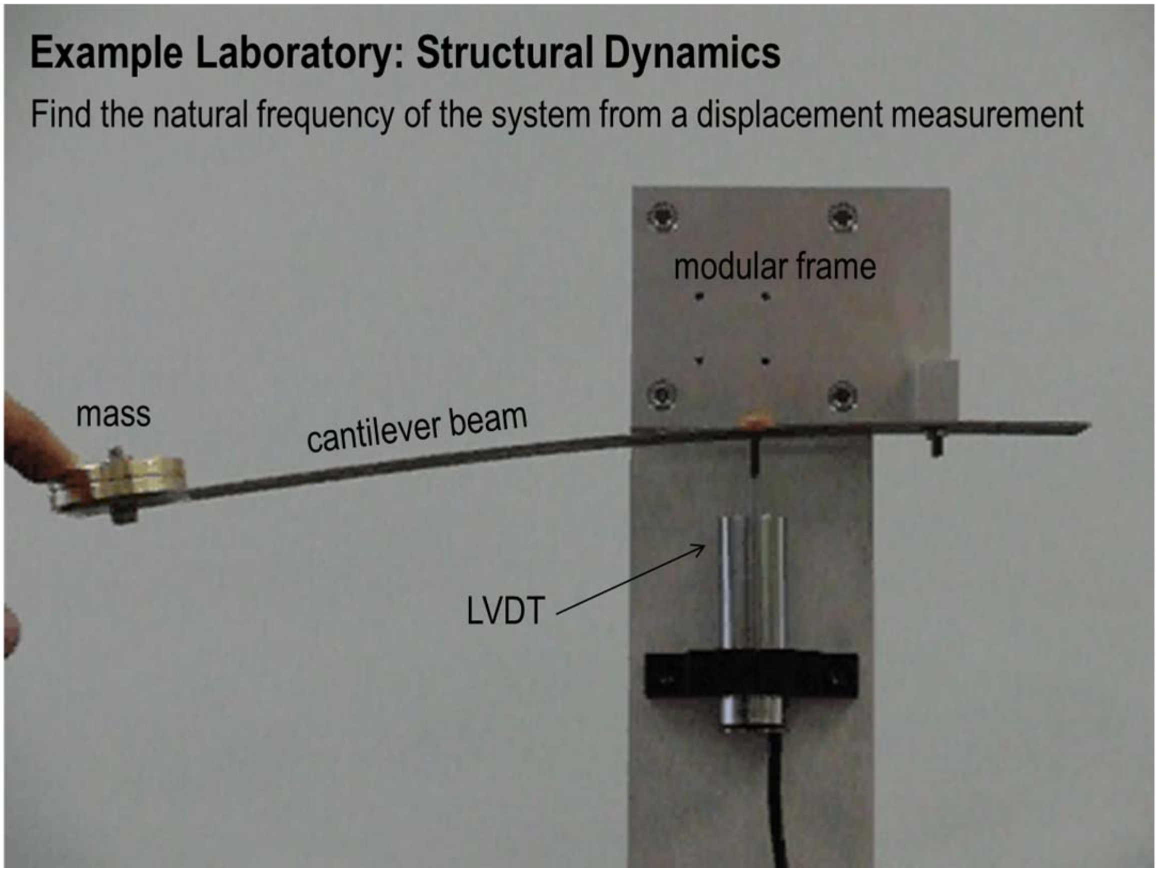

Figure 3. An image of an example laboratory activity using the modular load frame.

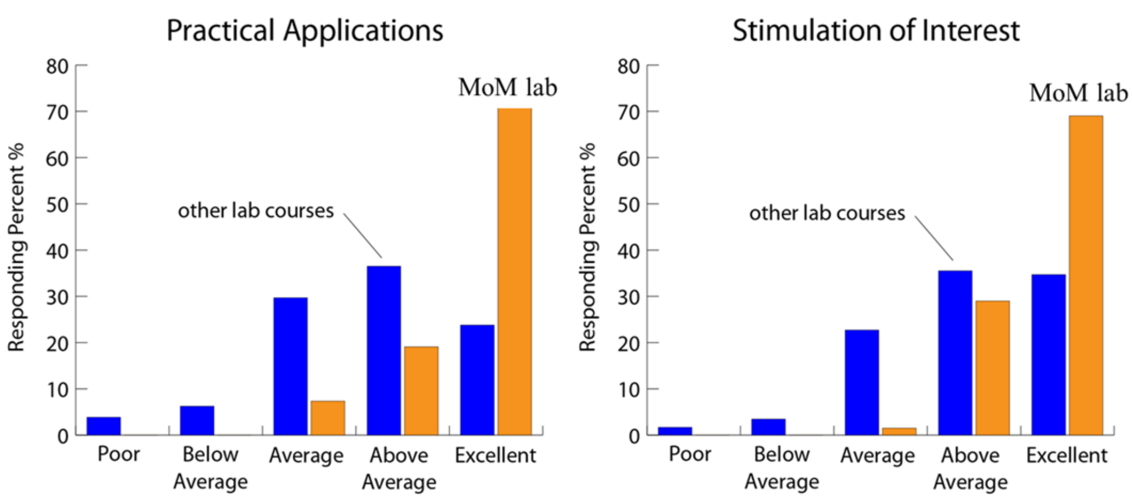

Figure 4. Student evaluation survey results. The results of the individual experiment model (orange) and shown against the last 10 semesters of all other laboratory courses in the same mechanical engineering department (blue) for the categories of “Practial Applications” and “Stimulation of Interest”.