Teaching Modern Data Acquisition Systems with a Departmental Requirement for Student Laptop Ownership

Stephen T. McClain
The University of Alabama at Birmingham
Department of Mechanical Engineering
BEC 358B, 1530 3rd Ave S
Birmingham, AL 35294-4461
smcclain@uab.edu

Bruce Cain
Mississippi State University
Department of Mechanical Engineering
P.O. Box ME
Mississippi State, MS 39762
cain@me.msstate.edu

Abstract

The undergraduate laboratory sequence in mechanical engineering (ME) at Mississippi State University (MSU) begins with ME 3701—Experimental Orientation, a one-hour laboratory focusing on engineering measurements, instrumentation, and modern data acquisition (DAQ) systems. Instruction and student projects in ME at MSU concerning modern DAQ systems have changed considerably in past five years. One driving force in changing the DAQ instruction is the departmental requirement of student laptop ownership. Modern DAQ systems are currently introduced using National Instruments, Inc., PCMCIA data acquisition cards and DAQ signal accessories hosted by the students' laptops. Using the students' laptops with department owned PCMCIA DAQ cards has eliminated the need for large DAQ laboratories, has increased hands-on DAQ instruction, and has allowed expanded use of DAQ systems in ME 3701 and the other undergraduate laboratories. With the experience gained in the undergraduate laboratories, current graduate students are using their own laptops and the PCMCIA cards (on a check-out basis) to perform research. The history of DAQ instruction in ME at MSU, the current DAQ instructional methods, and benefits of the current ME 3701 pedagogy to the other ME laboratories and graduate instruction are detailed.

Introduction

Laboratory sequences in many mechanical engineering programs are arranged for each individual laboratory to support a specific class, such as fluid mechanics, solid mechanics, or heat transfer. Alternatively, the objective of the mechanical engineering (ME) laboratory sequence at Mississippi State University (MSU) is to teach students experimental design, which includes transducer selection, computerized data acquisition system usage and programming, uncertainty analysis, and data reduction techniques. To achieve the goal of teaching experimental design, the undergraduate laboratory sequence in ME at MSU consists of three, one-hour laboratories: ME 3701—Experimental Orientation, ME 4721—Experimental Techniques I, and ME 4731—Experimental Techniques II.

In ME 3701, students study engineering measurements, transducers, and data acquisition systems. Students perform eight to ten experiments concerning electrical and mechanical measurements such as voltage, current, resistance, fluid velocity, strain, force, torque, pressure and temperature. While these experiments are similar to the types of experiments performed in class-support laboratories, the experiments focus on the instrumentation and the measurement/data acquisition techniques. The theory of the experiments is considered a secondary, but still very important, issue.

In ME 4721, students learn uncertainty analysis and experimental design using uncertainty-analysis techniques. While considered a laboratory, ME 4721 is really half lecture and half laboratory. The first half of the semester is spent teaching general and detailed uncertainty analysis, and the second half of the semester is dedicated to projects. Students, in groups of three or four, are required to perform three projects in ME 4721. One project is a design project requiring the students to design an apparatus and select instrumentation and test methods to minimize the uncertainty of an experiment. The other two projects are larger in scope than the experiments performed in ME 3701 and require detailed uncertainty analysis of the results. The results of all projects are reported in formal oral and written reports.

In ME 4731, the students are required to use the information acquired in ME 3701 and ME 4721 to design, build, and run experiments. Students, in groups of three or four, normally run four experiments in ME 4731. Two experiments are two-week experiments and two are five-week experiments. In the two-week experiments, students in groups of three or four are assigned an existing experimental apparatus and an experimental objective. The purpose of the two-week experiments is for the students to demonstrate the ability to use an existing apparatus and design an experimental procedure to achieve an objective. The students must then execute their procedure, analyze the data, determine uncertainties, and report the results.

In the five-week projects, students in groups of three or four choose an experimental objective. The students are given a list of about 30 experiments that have been approved as five-week projects. Half of the projects concern material behavior or solid mechanics, and half of the projects are related to heat transfer or fluid mechanics. The groups must complete one materials/solid mechanics five-week project and one heat transfer/fluid mechanics five-week project.

For each experimental objective, the groups are expected to select the apparatus construction, materials, instrumentation, and test plan that minimize the expected uncertainty in their result. The designs are presented in a formal proposal. After the formal proposal, the students must build the apparatus, run the experiment, analyze the results and uncertainties, and present the results in formal oral and written reports.

Instruction and student projects in the ME laboratory sequence at MSU have changed considerably in past five years. One driving force in changing the laboratory instruction is the departmental requirement of student laptop ownership. In 1999, the College of Engineering began requiring undergraduate student computer ownership or leasing. The Department of Mechanical Engineering added the requirement that all mechanical engineering students must either own or lease a laptop computer beginning with the semester in which the student enrolls in the first thermodynamics course.

While only a few mechanical engineering departments require student computer ownership, even fewer require student laptop computer ownership [1]. Requiring student laptop ownership presents many interesting problems and opportunities [2]. The history of data acquisition system instruction in ME at MSU, the new methods used for teaching data acquisition systems using the students' laptops, and opportunities created in the classes or laboratories following data acquisition system instruction are discussed in the following sections.

History of DAQ Usage and Instruction

Before 1997, the available data-acquisition equipment was not sufficient for all ME students to acquire adequate hands-on training. The department owned three data-acquisition computers with Omega, DAS-20 boards running either EasyTest XL or in-house generated BASIC programs. One data-acquisition system was purchased for each of the undergraduate laboratory rooms in the mechanical engineering building: the Materials Laboratory, the Heat Transfer Laboratory, and the Automation and Dynamics Laboratory.

Although the DAS-20's were old, their performance was acceptable for undergraduate instruction. The software, however, was unacceptable. The EasyTest XL software was difficult to learn and use, not customizable, and not widely used in industry. Programming the data acquisition systems using BASIC made the systems customizable but was very time consuming. Data-acquisition programming using BASIC was also not a job-skill that was highly requested by industry. LabVIEW drivers for the DAS-20's were also unavailable. Because the software available for data-acquisition was so antiquated, the best data-acquisition experience students received was running BASIC programs that instructors or research faculty had previously written.

In 1997, the ME department hired an undergraduate laboratory manager. Along with teaching the undergraduate laboratories and purchasing, running, and maintaining the lab equipment, one of the main purposes of hiring a laboratory manager was to update the undergraduate laboratory data-acquisition capabilities and instruction.

As part of updating the laboratory data-acquisition capabilities, the three old data acquisition systems using DAS-20's were replaced with three 300 MHz, Pentium II's with National Instruments (NI) PCI-MIO-16XE-50 data-acquisition cards running LabVIEW. To make the systems versatile, CB-68 or SCB-68 connector blocks were enclosed in Plexiglas boxes. Banana plugs were then mounted on the outside of the Plexiglas boxes and connected to the connector block to create easy access to the eight differential-analog-input channels and two analog-output channels. The entire systems were then placed on rolling carts. An image of a rolling-cart system is shown in Figure 1. Along with the new desktop systems, a 200 MHz, Pentium II, laptop was purchased with a DAQCard-16XE-50. The new systems were a marked improvement in laboratory capabilities and in ease of use. A significant amount of effort was spent updating existing equipment to be controlled and analyzed using the new data-acquisition systems.

Figure 1. Rolling-Cart DAQ System used for Laboratory Monitoring and Control

While the new systems made the undergraduate laboratories more effective and active, students still did not have considerable hands-on experience learning and programming data acquisition systems. In ME 3701 students received one three-hour lecture concerning modern data-acquisition systems. At the time, student enrollment in ME 3701 was about fifteen to twenty per section with two sections per semester. Because the department could not afford a computer lab dedicated to data-acquisition instruction, the three undergraduate DAQ systems and two research DAQ systems were rolled into a classroom for the students to use. This allowed one DAQ system per three to four students.

During the lecture, the DAQ Laptop was connected to a projection system for the instructor to use. Students were instructed on the major components of modern data acquisition systems and were presented an overview of LabVIEW. Following the instructors lead from the overhead projection system, the student groups were then required to write a brief LabVIEW program or virtual instrument (VI). The VI was expected to continuously sample from a channel connected to a transducer, display the value on a waveform chart, and then write the value to a spreadsheet file. While the new instruction methods were a big improvement, one lecture was not sufficient and the student groups were too large for all students to receive adequate instruction.

In 1999, the departmental requirement for student laptop ownership created a new mechanism for teaching data acquisition systems and LabVIEW programming. Along with the departmental requirement for student laptop ownership, a college-wide site license was purchased for LabVIEW. Because all of the students would have laptops with LabVIEW software, a new data-acquisition system pedagogy was adopted using the student laptops, data acquisition PCMCIA laptop computer cards, and specialized break-out boxes. Six DAQCard-1200 and six DAQ Signal Accessories were purchased from National Instruments for teaching data-acquisition systems and LabVIEW programming in ME 3701. The basic setup of the laptop DAQ systems is shown in Figure 2.

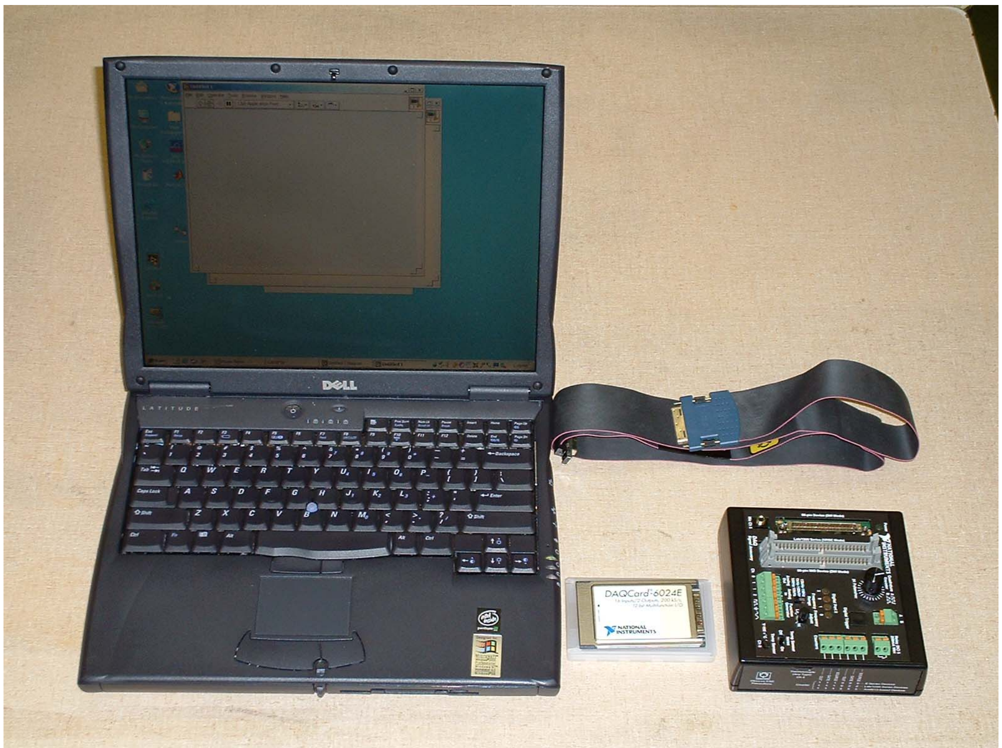

Figure 2. Basic Student DAQ Instruction Setup

The DAQ systems were incorporated into ME 3701 using an introduction lecture and two experiments that required student programming. In ME 3701, students enjoyed the hands-on data acquisition instruction. Since they were using their own laptops in the laboratories, the hands-on instruction also made the students feel as though they were getting the most education out of their expensive laptop computers.

The students' biggest complaint was that groups of three during the introduction lecture were too large. It was found that during the introduction lecture, only one student out of the group (usually the owner of the laptop used by the group) received adequate instruction. The second student paid attention, but did not receive adequate hands-on time to retain the instruction. The third student either received the same experience as the second student or did not pay any attention at all.

To make matters worse, in 2000 the undergraduate laboratories experienced an increase in enrollment. In previous semesters, the two sections of ME 3701 averaged about eighteen students. In Fall 2000, twenty-five students enrolled in one section, while twenty enrolled in the other. By supplementing some groups with the rolling-cart DAQ systems, group size was limited to three students, but the students using the rolling-cart DAQ systems did not report the same fulfillment associated with using their own laptops in their education.

In 2001, six DAQCard-6024E's and six Signal Accessories were purchased in addition to the existing set of DAQCard-1200's. These new DAQ cards finally provided the resources to teach data acquisition systems and LabVIEW programming with two person groups. The pedagogy currently used in ME 3701 is described in the next section.

Use of DAQ Systems in Current ME 3701 Instruction

Data acquisition techniques are introduced in ME 3701 over a the first half of the semester by integrating LabVIEW and DAQ programming instruction with our more traditional experiments in the performance and application of various transducers. Beginning with the first week, the students are walked-through the in-class installation of LabVIEW on their laptop computers with homework assignments to work through the accompanying LabVIEW Tutorial. Each subsequent week, the students are shown how to program LabVIEW to plot various math functions using a real-time clock, how to add various customized user-interface objects, and how to reliably save data to file. Each week additional detail is added to the program, or VI, from the previous week, so that by mid-semester each student has programmed a versatile plotting and data-saving VI with controllable time-steps between data points. These VI's are assigned as homework problems that closely follow the instruction given the previous week in class.

By mid-semester, each student group is assigned two experiments requiring LabVIEW for data acquisition. Each group writes and modifies their own VI before the experiment, and then in-class they are instructed to modify their VI to accept input from the PCMCIA based DAQ Cards instead of the "math function" they used earlier. This change from "math function input" to "voltage data input" simply requires the replacement of one "math object" in the VI with a "DAQ object", along with a "windows based configuration" of their DAQ Card once it is plugged into their laptops. These "experiment ready" VI's require only about 30 minutes of instruction to modify their before-class VI's, so that data can be collected during the same lab session. We've found that this incremental introduction to LabVIEW, from a blank page to a fully functioning DAQ VI, works well as it exposes the students to increasingly complex issues of DAQ over an extended time frame. It also helps that each student in each group is required to actually "take data" with his/her laptop

An example of one experiment requiring LabVIEW data collection is the determination of the "time constant for a thermocouple". In this experiment a type K thermocouple is heated to about

200 °C, then allowed to cool in ambient air while the LabVIEW VI collects the thermocouple response. If the ambient air is relatively undisturbed by drafts, the resulting cooling curve is exponential. Figure 3 below shows the equipment used in this experiment, including a hand-held digital thermometer for obtaining "reference temperatures" for software simulated cold-junction compensation. Shown on the laptop screen are typical plots of Temperature vs. Time (top) and ln(T) vs. time (bottom), where the linear portion of the bottom plot is clearly visible. This linear portion of the curve is used in subsequent analysis to estimate the time constant.

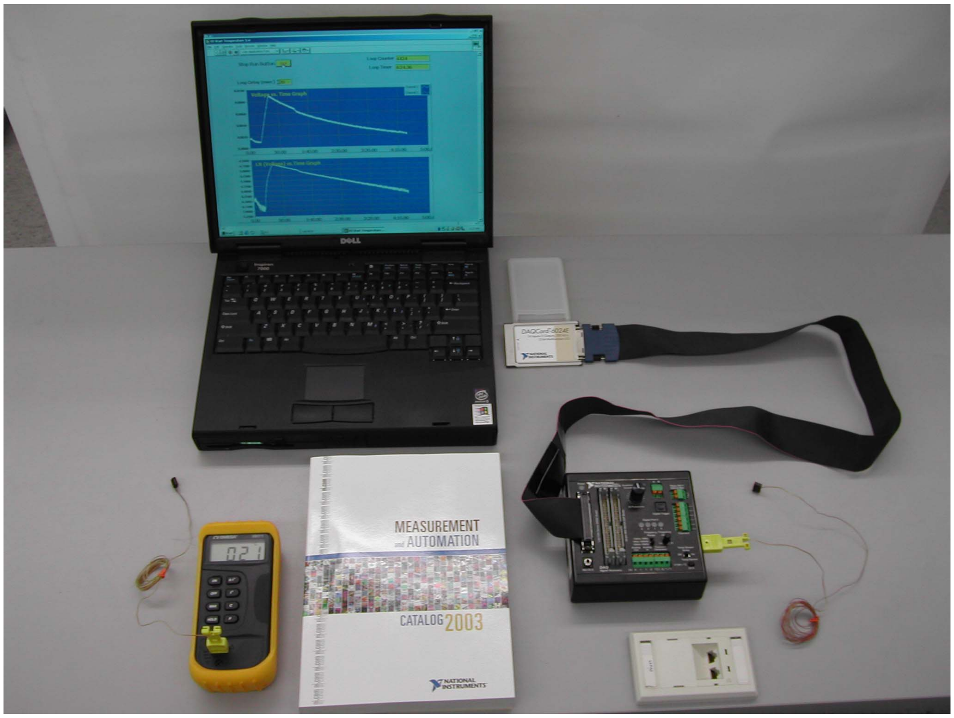

Figure 3. Example Student DAQ Setup for Instruction in ME 3701

A significant advantage of this experiment is that it is easy to setup, and requires only about 5 minutes to collect the data. Hence if the ambient air is disturbed during data collection, the experiment can be quickly repeated until a good "linear plot" is obtained. In this experiment we require each group member to use a different thermocouple (of the same general construction) so that various in time-constants are obtained. Analysis is then required to quantify not just the time constant, but statistical differences for the group of thermocouples.

Student progress with LabVIEW and DAQ techniques are assessed through homework problems, exam questions, and a hands-on demonstration of LabVIEW knowledge. The homework sets require evidence of individual LabVIEW programs that function properly, while exam questions deal with general question of DAQ programming and hardware functions. The final homework set requires each student to plug-in a DAQ Card and run an "instructor provided VI" to collect and save data to file. The student must successfully collect the data and answer questions specific to the functioning of the VI and the meaning of the data set collected.

Overall, most students appreciate the LabVIEW and DAQ instruction, as it provides hands-on experience with a sophisticated DAQ package, and it gives them portable capabilities that they can use in other classes and laboratories.

Use of DAQ Systems in Classes Following ME 3701

After ME 3701, the students are well prepared to program in LabVIEW and to use the laptop DAQ systems in their following classes. In ME 4721, students mainly use the systems with preexisting virtual instruments for the completion of experiments. The main focus of ME 4721 is uncertainty analysis, so very little LabVIEW programming is performed. Since the main focus of ME 4721 is uncertainty analysis, any programming required in ME 4721 pertains to automatic uncertainty calculation in LabVIEW. A sample virtual instrument that is often required of students is shown in Figure 4. The sample vi takes in a waveform, a one-dimensional vector of channel readings, and calculates the mean value and the random uncertainty, $tS_x / \sqrt{N}$, where t is the Student's t value based on the level of confidence and the degrees of freedom, S_x is the sample variance, and N is the number of samples in the waveform.

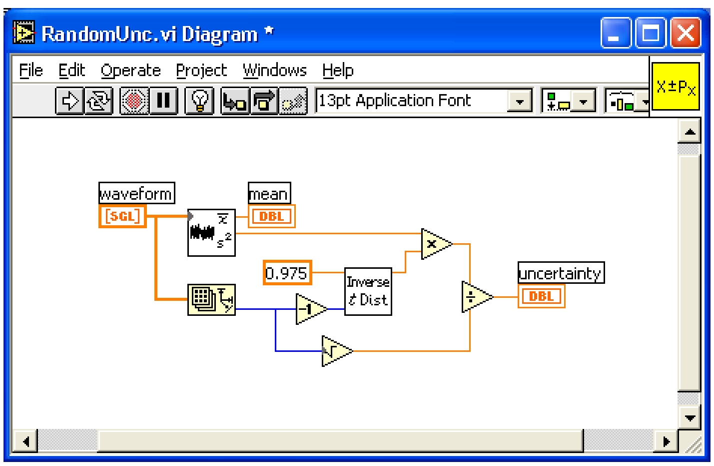

Figure 4. Random Uncertainty Virtual Instrument

The laptop DAQ systems and LabVIEW are used extensively in ME 4731. In Fall 2001, students were required to write LabVIEW programs and to use their own laptops to acquire data for their two-week projects. The students were also highly encouraged to use the laptop DAQ systems on a "checkout" basis to complete their five-week experiments. Students were allowed to checkout a DAQCard and either a Signal Accessory or a BNC-2110 connector block with BNC to gator-clip cables overnight or over a weekend.

Over the three years that the DAQCards were available to be checked out for use in ME 4731, they were used in only about one-fifth of the five-week projects. Because of the LabVIEW programming, many student groups perceive experiments requiring DAQ systems to be more work than experiments not requiring DAQ systems. The groups that did choose to use the DAQ systems, however, usually produced extraordinary results and found the experience very rewarding. Examples of ME 4731 projects using the laptop DAQ systems are: (1) a project to determine the velocity of an automobile using the Doppler Effect on the measured horn frequency, (2) a project to determine the feasibility of creating an automatic shut-off system for a clothes-drier by measuring the humidity ratio of the air exiting the drier, and (3) a project to determine the thermal diffusivity of aluminum using a transient heat transfer method.

In the Spring of 2001, an ME 4731 student group designed, built, and calibrated a model-rocket-engine test stand. The group then tested several model rocket engines for maximum thrust, average thrust, and total thrust time. The group could have only completed the project with the laptop DAQ systems. The students constructed the test stand, checked out a DAQCard, wrote the virtual instrument, and performed the engine tests. The details of the experiment are presented in Ref. [3]. An image of an engine test and a sample thrust curve generated during the project are presented in Figure 5.

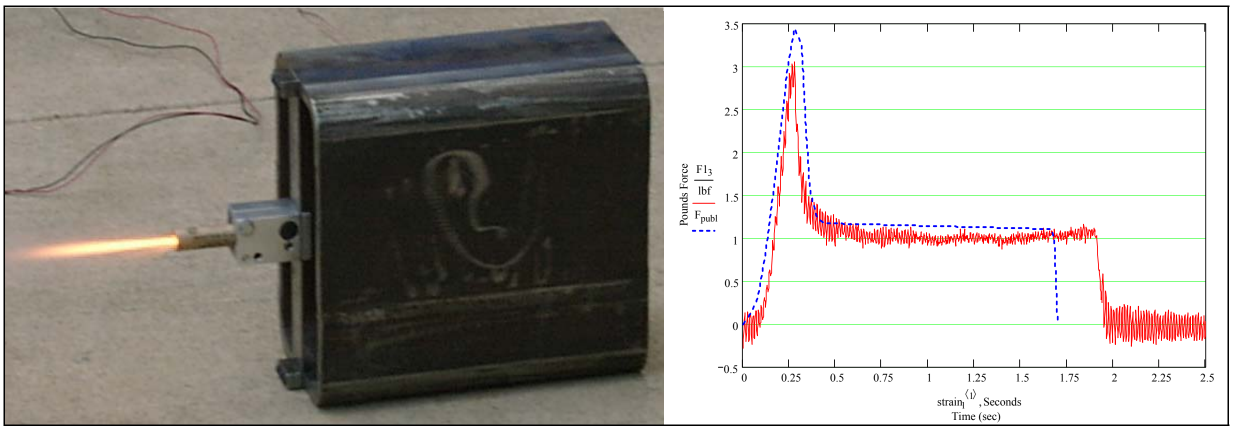

Figure 5. Digital Image of Model Rocket Engine Test with Test Results

The laptop DAQ systems have also been used in other design classes as well as other student projects. In the Fall semester of 1999, the MSU MiniBaja team constructed a rear-wheel dynamometer to test the performance of the car constructed for the SAE MiniBaja Competition [4]. The team did not have the funding to purchase a dedicated data acquisition system, so the students checked-out a laptop DAQ system. The team investigated the performance of a continuously-variable transmission system and tested engine performance using different engine oils.

The laptop DAQ systems have also been made available to graduate students. The strong basis in undergraduate DAQ education and the availability of the checkout DAQ systems has benefited graduate students at MSU. One student used a "check-out" system for her research regarding the use of uncertainty analysis in the design of a crank-slider mechanism. Using the DAQ system, measurements of the actual position of the slider versus the crank angle were made during crank-slider operation. These measurements were then used to demonstrate how uncertainty analysis could be used for optimization in the design process [5]. A second graduate student used a "check-out" DAQ system to evaluate obstacle detection systems for lift trucks. Several combinations of detection sensors were tested for area coverage and obstacle range [6].

Conclusions

The undergraduate laboratories and laboratory instruction in ME at MSU have changed considerably since 1997. The departmental requirement for undergraduate student laptop ownership in the ME department at MSU had a profound effect on teaching practices in the undergraduate laboratories. In the introductory instrumentation laboratory, students are instructed on modern data acquisition system usage and programming and are now using their own laptop computers with departmentally owned data acquisition cards, break-out boxes, and LabVIEW software. The increased hands-on experience has been embraced by the students and has provided an extra justification for the expense incurred by students because of the laptop ownership requirement.

The data acquisition system instruction in the introductory laboratory has influenced instruction in the subsequent laboratories. The DAQ system instruction has greatly expanded the student design options in the experimental design laboratory. Student groups that choose to use the data acquisition systems are generally very excited about their projects and produce excellent work. The benefits of undergraduate DAQ system instruction are also appearing in extracurricular student projects and in graduate student research.

Acknowledgements

The authors would like to thank W. Glenn Steele and the Department of Mechanical Engineering at Mississippi State University for their support of these teaching activities. The authors would also like to thank B. Keith Hodge and Anne S. McClain for their help and suggestions concerning the paper. The help of Luke Nasson, the Electronics Technician for the Department of Mechanical Engineering at MSU, is also greatly appreciated. Lastly, the authors would like to thank their students for their enthusiasm, dedication, and professionalism.

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STEPHEN T. MCCLAIN

Stephen T. McClain is an Assistant Professor at the University of Alabama at Birmingham. He received his B.S. in mechanical engineering from The University of Memphis in 1995, and he received his M.S. (1997) and Ph.D. (2002) degrees in mechanical engineering from Mississippi State University. From 1997 to 2002, Dr. McClain was a Lecturer and Undergraduate Laboratory Manager in the Department of Mechanical Engineering at Mississippi State University.

BRUCE CAIN

Bruce Cain is an Associate Professor at Mississippi State University. Dr. Cain received his B.S. in nuclear engineering from Mississippi State University in 1979. He received his M.S. (1986) and his Ph.D. (1989) from the University of Illinois.