Increasing Undergraduate Laboratory Experiences

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Abstract

Use of higher level programming environments have made it increasingly easy to formulate theoretical solutions, but at the cost of distancing the students from understanding the physical phenomena. In an attempt to allay this, our undergraduate laboratory experiences have been increasing as our aerospace engineering curriculum undergoes modernization. Two laboratory classes of the upper division of the MSU curriculum have been moved ahead one semester in the current curriculum, and may be moved even further ahead. Although these courses are almost entirely experiential in nature, changes to the curriculum and rapidly changing technologies are necessitating some changes to the character and substance of these labs. These courses are being modified to provide general guidance in experimental methods and analysis, and to specifically provide an introduction to data acquisition and control of experiments directly related to analytical coursework. Lab classes continue to be a forum for individual research projects and seminar presentations. Individual laboratory experiences have also become an important part of three introductory courses taught in the freshman and sophomore years, with experiments ranging from simple exercises to complex analytical and experimental correlations. Additional laboratory experiences have been added to other traditional aerospace courses of the upper division. The motivation for increasing laboratory participation is detailed in this paper, and the impact of these changes is discussed. Course and departmental goals and objectives, and related ABET accreditation criteria are discussed, and the effectiveness of these efforts is assessed. The accommodation of undergraduate design-build-fly teams is discussed, and the potential for such competitions to provide a more complete laboratory experience is assessed.

Background

The use of computational tools like Mathcad[1] and programming environments such as MATLAB[2] and LabVIEW[3] have made it increasingly easy to program complex solutions to analytical problems. However, the use of such tools has increasingly distanced the students from understanding the physical phenomena under consideration. It becomes increasingly simple to express complex problems succinctly, but errors in logic or in simple input to computations become more difficult to detect. When computational or programming abilities were built up slowly, using tried-and-true problem solving methodology, those computations and programs were considered suspect until coded and tested. For the most part, hand calculations were performed with the emphasis on insuring that a code could generate a known solution prior to trusting that solution on a more complex or unknown problem. As the use of Mathcad and other programs replaced the calculator, the tendency became to trust the equations to generate a correct solution. Where a problem is posed correctly, with all of the correct inputs, one would imagine that a correct solution would be an orderly consequence. However, because all problems have inputs and outputs that are signed and dimensioned quantities, even correctly posed problems

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with incorrect units can give answers that are misunderstood, or that are simply wrong. Just as the previous generation of slide rule users complained about the calculators giving incorrect answers to many decimal places, the fundamental consideration is that the engineer must have some basis for determining if computational results are realistic, or within reasonable uncertainty. There is no better substitute than experience to provide a basis for understanding fundamental relationships. This understanding can then allow an engineer to validate a computation or chain of calculations upon which further assumptions may be justified. Experiential learning, then, must be sought after not only to aid in maintaining interest and motivation for studying a particular field, but to aid in building up the basis for understanding fundamental principles. Toward this end, laboratory experiences have been included in introductory courses[4] in aerospace engineering at MSU. Much effort continues to insure that laboratory experiences are modified and updated continuously so that they remain valid and applicable to the program of study. Since the use of computers has compounded the difficulty in maintaining modern experiences that reinforce classical engineering fundamentals, it is appropriate that experiential learning continue to be emphasized in the manner in which the computer usage is emphasized--across the curriculum.

Experiential Learning

Two laboratory classes of the upper division of the MSU curriculum have been moved ahead one semester in the current curriculum, and may be moved even further ahead. Table 1 details the last major curriculum modifications as outlined by Rais-Rohani[4]. Further changes are being promulgated in response to a requirement to reduce the overall number of credit hours in all engineering programs. Though the current laboratory courses are almost entirely experiential in nature, changes to the curriculum and rapidly changing technologies are necessitating some alterations or modifications to the character and substance of these labs. These courses are being modified to provide general guidance in experimental methods and analysis, and to provide a specific introduction to data acquisition and control of experiments directly related to analytical coursework. In an effort to insure that students remain motivated to remain in their chosen field of study, introductory courses now begin during the first semester freshman year. There are experiential endeavors imbedded in each of three courses introducing aerospace engineering fundamentals, flight mechanics, stability and control, astrodynamics, propulsion, and structures. Several small experiments are also included in several aerodynamics and structures classes in the upper division, and several experiments are performed in a vibrations class. Nevertheless, the main laboratory experiences are imbedded in two laboratory classes of the upper division. Formerly taught during the senior year, these courses were moved ahead in the curriculum recently to make room for an expanded design course. A single semester, airplane design class has been replaced with a two semester course with emphasis on both aircraft and spacecraft design. Additionally, these courses are under consideration to be moved further ahead in the curriculum to make room or provide the necessary preparation for the transition to a two-track program with aero or astro emphasis. The total number of hours required for a degree will likely be reduced as a result of statewide university curriculum standardization. This has already posed problems with prerequisites—moving the courses ahead has forced the reconsideration of those prerequisites, to allow concurrent coursework instead. This has forced the reordering of some of the laboratory experiences to allow introduction of the analytical principles prior to attempting experimental validations. In some cases, laboratory exercises were made more extensive when electronics was eliminated from the curriculum, yet the dependence upon computers for experimental data acquisition and control mandates some fundamental instruction in the use of digital electronic devices.

In addition, moving the courses ahead in the curriculum has forced students to begin working on individual research projects for their “senior seminar” when they have just begun their upper division coursework that motivates them to choose a particular project. Changes to the two upper division laboratory courses have been initiated to make the first course a fundamental experimental methods course, with the second course being applied experimentation. Thus, the students will be better prepared to begin individual research and experiments after having been schooled in the fundamentals.

Table 1. Lab and Design Class comparison of the old and new ASE curricula

Year	Junior Year		Senior Year	
	Fall semester	Spring semester	Fall semester	Spring semester
Old	curriculum			
		Electronics **Electronics Lab**	**ASE Lab I**	**ASE Lab II** **ASE Design**
New	curriculum			
		ASE Lab I	**ASE Lab II** **ASE Design I**	**ASE Design II**

In order to accommodate non-traditional students and those students who take a semester off campus for internships or co-op work, the first laboratory course is being modified so that it can be taught as a web-based course[5]. Thus, much of the course will consist of simulations or review of documented experiments, with the operation of some physical experiments remotely via the web. The second course, however, will continue to be a forum for individual research projects and seminar presentations. If these courses become slightly less physically experiential in nature, they extend the laboratory into the virtual world of the web and the overall effect will be a definite gain in accessibility of the labs. Though the conduct of these two particular courses might become slightly less traditional, these course modifications have set the stage for further extensions of the laboratory experience into other courses. The university has invested a lot of time and resources to insure that WebCT[6], a very valuable web-based classroom technology, is available for use in any class. The work by lab personnel to extend and enhance the offering of the regular upper division laboratory classes through WebCT has provided experience in developing assignments uniquely adapted for this interface. It has become increasingly easy to introduce “lab assignments” into other courses using the same methodology as for lab classes.

As a test, there has been specific accommodation of several students who had rigid schedule conflicts as a test of the methods used to have students complete these assignments. Additionally, students from a previous class assisted in testing the implementation of some remotely controlled and simulated lab assignments. Although only preliminary results are available from these tests, those results have been positive. These students were able, for example, to review lectures only as online presentations, and accomplish the related experiments without additional instructions in most instances. Where there were difficulties in understanding tasks or intricacies of assignments, necessary modifications and additions to the online material were made as a direct result. The assistance of the spring, 2005 laboratory class has been solicited in testing all aspects of the online self-study modules, presentations, quizzes and programming simulations or tests. Tests completed through the first half of the spring semester have been very positive, and students have become much more interested in working on lab classes as a result. One graduating senior has decided to pursue graduate school work and has requested assignment as a teaching assistant with the class as a result of his assistance with our project modifications.

Individual laboratory experiences have become an important part of three introductory courses taught in the freshman and sophomore years, with experiments ranging from simple exercises to complex analytical and experimental correlations. During the past year, teaching assistants for those courses have also been trained in the fundamentals of using WebCT. Increasingly, assignments can be made, collected, graded and returned to individuals or subgroups within a class in short order using tools made commonly available to the WebCT developer. As was alluded to earlier, there have been additional laboratory experiences added to other courses, particularly structures and vibrations, that have been primarily physical in nature—building an apparatus or a structural component, testing, and reporting on the experiment. It is proposed that such experiments be introduced across the curriculum, with the laboratory personnel (teaching assistants and supervisory personnel) playing an increasingly common role in everyday instruction.

Motivation and Assessment

The motivation for increasing laboratory participation is apparent, but if such changes are to be introduced into more classes, there must be a consideration of problems that have been experienced, and lessons that have been learned. In the case of the lab experiments introduced in the three course introductory sequence, much has already been discussed by Rais-Rohani, Koenig and Hannigan[1]. Of note, though, is that the impact of the introductory courses is being realized, and students are being retained in aerospace engineering at a greater rate than prior to introducing these courses. It is difficult to determine if the experiments introduced in those courses are having a definite impact upon student retention, but it has been noted that students who have laboratory experience have displayed significantly greater understanding of fundamental principles in later classroom discussions and reports[7]. Although the course and departmental goals and objectives have been stated, and related ABET accreditation criteria discussed in course syllabi and outlines, some of those objectives and criteria have been difficult to assess. Introduction of team and individual projects has made the effectiveness of such efforts easier to assess in those courses where such are used.

Increasingly, the students have become more motivated by participating in events such as the American Institute of Aeronautics and Astronautics/Cessna/Office of Naval Research sponsored Design-Build-Fly (DBF) competition. At least for the freshmen, getting hands-on experience and being introduced to topics that are clearly ASE-related has increased their interest in those topics early in the curricula. While they are still taking prerequisite courses for their major discipline, they have typically not been made aware that these courses are directly related to their upper division courses. Their exposure in these activities brings them into contact with upper division students who make the association abundantly clear. The hands-on learning, coupled with their participation in work that requires ongoing problem solving and critical thinking goes a long way toward sustaining a high level of motivation for their major. During the current semester, there are no less than three such competition teams working toward their individual goals, with the addition of a team competing in the Society of Automotive Engineers sponsored HeavyLift competition and another team participating in the Association for Unmanned Vehicle Systems International sponsored Unmanned Air Vehicle design competition. These competitions have a clear potential to provide motivation to students, as well as to provide valuable experience, and they offer a clear benchmark of the progress of the program as a whole. Clearly, the competitions offer hands-on experience at a depth much greater than the average laboratory experience, even complex tasks that are specifically designed to be benchmarks[8]. Yet, such events also offer opportunities for individuals to recognize personal areas of interest, and to experience individual growth through team participation. The design experience invariably leads to experimentation to validate design assumptions, or to gather data upon which to base optimization decisions. The potential for these experiences to be exploited for their illustrative value is just beginning to be realized.

The MSU aerospace students currently have several years of competitive design experience that has taken teams into the top ten in final competitions on the international level. The documentation of experiments and analysis that led up to final design, and problems that were surmounted during the final phases of building and flight testing offer great depth of learning that can be returned to the classroom. There has been a steady accumulation of design optimization, refinement, and test data that can also be returned. It takes a concerted effort, however, to do so, as documentation and presentation of the laboratory experience was probably the last thing on the mind of those students who were focused on completion of their team's competition aircraft.

Current and Future Development

A complete survey of laboratory experiments conducted over the past several years, and a preliminary review of the design-build-fly projects has revealed a host of experiments that can be introduced into fundamental aerospace engineering classes. It is the intention that these experiments be documented and presented to the instructors of the various classes for inclusion in the next course offering beginning in Fall 2005. These topics have been reviewed and an assessment made that most of these exercises can be easily setup through WebCT for immediate implementation of these experiments. In addition, several experiments already being conducted outside lab classes can be documented and managed in a similar manner. In some cases these exercises will duplicate portions of experiments conducted in lab classes for calibration and other illustrative purposes. Such exercises will provide familiarity with laboratory equipment through hands-on or virtual interaction and use of facilities. The following is a listing of the experiments that have already been developed and conducted as special topics or for occasional laboratories, and are now being refined and for which WebCT documentation is being prepared.

While in the past, lab students have typically done these only once, virtual access will provide opportunity for multiple experiences with each activity. Some of these activities can be established as actual simulations, where the associated hardware is not operated, but their operating characteristics can be explored. Others can be set up as remotely operated experiments that removes restrictions to physical proximity. A group of students do not have to actually leave a classroom, for example to execute a laboratory experiment. This will become increasingly important when equipment has to be set up in a remote location due to building renovations and repairs. Operations of an apparatus that is too complex for accurate simulation and otherwise not suitable for remote operation may be effectively utilized through sophisticated demonstrations that can be stepped through, and made to approximate a real-time simulation or operation.

Flight mechanics/stability & control:
- Velocity and angle-of-attack control of a portable wind tunnel
- Startup, control and monitoring of a large subsonic wind tunnel
- Static longitudinal stability study with a force model
  - Obtaining stability derivatives
  - Aerodynamic center determination
- Determination of the fixed stick neutral point of an aircraft from flight test data
- Control of computer peripherals with fundamental and higher order programming

Fluid mechanics:
- Pressure measurements in a converging nozzle (Bernoulli's principle)
- Velocity measurements with a pitot-static probe and water manometers
- Velocity profiles in pipe flow
- Volume flow rate through a pipe

Aerodynamics:
- Flow through a converging/diverging nozzle
  - Schlieren imaging, pressure distribution, design validation
- 1-D and 2-D boundary layer measurements on a flat plate
- Flow measurements with hot wire anemometry
- Boundary layer profiles on a spinning plate
  - Hot film & Laser-Doppler measurements
- Pressure distribution about an airfoil at an angle of attack
  - Water manometer and transducer measurements
  - Theoretical predictions of viscid/inviscid flow solvers

Propulsion:
- Pulse-jet engine
  - Pressure and temperature distributions
  - FFT analysis
- Hybrid/Gaseous rocket engine
  - Thrust determination
  - Nozzle degradation effects
  - Combustion considerations

Vibrations:
- Harmonic vibration of a cantilevered beam
  - Euler & Dunkerly calculations of natural frequencies of loaded/unloaded beam
  - Computational determinations with Myklestadt's Method
  - Finite element method modal analysis with Unigraphics
  - Experimental verification of modal analysis

Harmonic vibrations of a propeller blade
Modal analysis with Unigraphics
Experimental verification of modal analysis
Vibration/displacement measuring instruments
Piezo & Spring mass damper accelerometers
Linear variable differential transformers

Structures:
Aluminum beam stress experiment – shear center determination
centered/uncentered loading of a symmetric beam
determination of the shear center of an non-symmetric beam
Failure mode shapes of stable columns
predicting failure of stable columns with varied end conditions
Stress/strain/deflection versus load for a cantilevered beam
Mechanics of materials investigation with a strain gage
Transducer design experiment

General/special topics:
Using a computer data acquisition card
Digital/analog input/output
Counter/timer operations
Signal analysis
Frequency and amplitude determination
Signal to noise ratio
Aliasing
Portable data acquisition devices
data logging/event reconstruction
GPS tracking

In addition to the aforementioned laboratory exercises, there are a host of experiments that have been conducted for the design-build-fly efforts suitable for adapting into general usage. If actual flight vehicle design is incorporated into the curriculum, these exercises would be essential lessons to be learned from past endeavors.

Propulsion:
Thrust efficiency of various propeller/electric motor combinations
Drag reduction through the use of cowlings, fairings, and fillets
Form drag/control system interference prediction/analysis

Structures:
Strength to weight testing of aircraft structures
Bending and torsion testing of aircraft structures

Aerodynamics:
Airfoil selection and wing design
Effects of wing warping versus control deflection

Controls:
Sizing of control and stabilizer surfaces
Ground handling and ground stability

General:

Flight data recording and analysis
Event reconstruction

Implementation plans

Many of these exercises have in fact, been converted to an online format as part of the laboratory course modifications. These are being tested in the spring 2005 semester, and resulting problems are being actively resolved prior to their being offered as exercises for incorporation into other classes. It is anticipated that a majority of these exercises will be incorporated into classes within the next year, and the positive effects of these additional laboratory experiences in those classes will be realized, based on past experience. It is anticipated that the student satisfaction with laboratory components will improve with the direct correlation of laboratory and analytical work. In the past there has been a perception by graduating seniors that perhaps lab classes were merely a hurdle to be cleared on the path to graduation, though time and again, graduates returned to express gratitude for lessons well learned from the lab classes. With the laboratory personnel providing direct support to the instructors of classes, including setup, conduct, and grading of laboratory exercises, preliminary discussions reveal no opposition to this planned expansion of experiential learning into traditional lecture courses.

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