AC 2007-189: ENGINEERING LABORATORY EXPERIMENTS – AN INTEGRATED APPROACH OF TEACHING THE INTRODUCTORY ENGINEERING COURSE

Atin Sinha, Albany State University

Atin Sinha is the Regents Engineering Professor and Coordinator of the Engineering Program at Albany State University. He received his Ph.D. in Aerospace Engineering from the University of Tennessee Space Institute in 1984. He had worked in aeronautical research and industry (National Aerospace Laboratory-India, Learjet, Allied-Signal) for 12 years before moving to academia in 1990. He is also a Registered Professional Engineer in Oklahoma. Currently, he is engaged in motivating undergraduate students in inquiry based learning through laboratory experimentations.

Engineering Laboratory Experiments – An Integrated Approach of Teaching the Introductory Engineering Course

Abstract

In an effort to introduce more realism and familiarity with the current manufacturing and testing equipment at an early stage of students' engineering education, the introductory level engineering course offered by Albany State University's transfer engineering program with Georgia Institute of Technology was transformed from a 3 hour lecture only to a 2 hour lecture and a 3 hour laboratory class where students go through a series of hands-on projects in a multidisciplinary laboratory setup established from a grant from the Department of Education. The LEGO Mindstorm robots, FLOTEK 1440 wind tunnel, PC TURN 55 CNC machine, SolidWorks 3D software with Dimension 3D Printer rapid prototyping machine are primarily used in the laboratory component of the "Principles of Engineering Analysis and Design" course taught at the sophomore level which carried 30% of the final course grade. The laboratory class introduced in 2001 has become a strong motivational tool for our engineering students inspiring them to continue with the upper level courses. Apart from exposure to multiple equipment and software, students gain an insight into how a task can be accomplished by first defining the problem, then breaking it down to workable steps and apply known information to solve them to arrive at an acceptable solution.

Introduction

Albany State University (ASU), located in Southwestern part of Georgia, conducts the Regents Engineering Transfer Program (2+2) and Dual Degree Program (3+2) to transfer students to Georgia Institute of Technology (Georgia Tech) under a cooperative agreement. Over 90% student of ASU belong to the African American community as well as the entire group of engineering students which currently stands at around 50. ASU follows an open enrollment policy for engineering studies in spite of an entrance requirement suggested by Georgia Tech. On an average 2 to 3 students per year transfer to Georgia Tech with 5 transferring in the year 2005-06. As of fall '06, 84.4% of ASU students that had transferred to Georgia Tech since the beginning of the program in mid-80's, have either graduated from or are currently enrolled in one of the 5 different engineering majors. The range of the comparable figure denoting the success rate for transfer engineering programs of all other institutions in Georgia is 72% to 92%, which validates the quality of our program. The students complete the core courses in humanities, mathematics and science as well as some freshman and sophomore level engineering courses in order to have a seamless transfer to the junior level at Georgia Tech. As is customary in most if not all undergraduate engineering programs, ASU also conducts an introductory level course for the engineering students. Unlike most other programs where this course is taught at the freshman level, our course called "Principles of Engineering Analysis and Design" is taught every fall semester at the sophomore level with Pre-calculus as a prerequisite.

The Original Course Structure and Reasoning for Change

Engineering educators have grappled with many topics that deserved to be included in the introductory engineering course[1] since it became common place in the undergraduate curriculum. Aside from the discipline specific introductory courses, in the vast majority of

engineering programs, this course is often used to introduce students to the engineering career opportunity, course requirements, survival skills, team work, communications, ethical practices, and sometimes brief exposure to CAD and computer programming. In ASU because of existence of separate freshman level courses on Engineering Graphics and Engineering Computing which preceded the Principles of Engineering Analysis and Design course, those topics were not included. However, ASU course was designed to reinforce concepts learned in Algebra and Trigonometry as well as basic topics in differentiation, integrations, linear algebra, complex variables with application oriented problem solving. Also included are the fundamentals of Statics, Electric Circuits, thermodynamics and engineering economics. Field trips to local industry or speech by a guest lecturer allowed students to have a glimpse of real life work experience of practicing engineers. The course was taught as a 3 credit hour lecture only course till the year 2000.

In recent years in an effort to provide realistic and engaging learning experience for the freshman and sophomore level students, an alternative form of courses have been designed and adopted with predominantly hands-on laboratory experiments. Examples of such courses based on LEGO Robotics[2] for the entire freshman class to rapid prototyping and CNC machining[3] for the mechanical, aerospace, civil engineering and virtual laboratory experiments[4] for civil and environmental engineering have proved to be successful in making students excited about learning the basic concepts needed in future math and physics courses thereby helping to improve the retention rate of engineering students.

At ASU, in the spring of 2001, a set of 8 Lego-Midnstorm programmable robots were acquired from a grant from the Georgia Space Grant Consortium, a funding agency of NASA. Also, in March 2001, a proposal was submitted to the Department of Education's Minority Science and Engineering Improvement Program (MSEIP) for a grant entitled "Gaining Rapid Awareness and Preparedness in Engineering Studies" which was approved in August that year. Under this proposal funding was allocated to establish an Engineering Laboratory consisting of a handful of computer controlled testing and manufacturing equipment. The original intent of the Department of Education grant was to develop the laboratory so that the students can gain an insight into how engineers use a combination of theoretical and experimental methods to solve real life problems. A secondary objective was to motivate incoming students as well as high school juniors and seniors to the rewards and challenges of an engineering career by providing them an opportunity of conducting experiments in industry standard equipment.

Once the laboratory equipment started arriving and being installed and new experiments and projects developed, it became apparent that the best vehicle to carry out the missions of the grant will be to use the "Principles of Engineering Analysis and Design" course to introduce students to the new equipment and experiments. Accordingly, the 3 credit hour lecture course was modified to a 2 hour lecture and a 3 hour laboratory course and implemented in the fall of 2001. The first year, only the robots were used in the lab section of the course as the equipment in the Department of Education grant had not arrived yet. In the subsequent years, the new equipment were phased in the course as and when they were installed.

New Equipment and the Experiments

The first equipment to arrive was the PC Turn 55 CNC lathe in late fall of 2001 which was followed by FLOTEK 1440 wind tunnel in the early spring of 2002. Two more equipment, a bench top universal testing machine and a rapid prototyping machine were acquired and installed by the end of spring 2003. A metallurgical microscope and oven were added before the grant ended in the 2005. Since each of these equipment are controlled by software operated from Windows environment, a set of 8 desktop and 8 laptop computers with internet access were installed in the newly established Engineering Laboratory. The computers were equipped with a wide variety of software from usual application software to commercially available special purpose software, viz., MATLAB, SolidWorks, LabVIEW. Two other software, RoboLAB and WinCAM, are also installed in the lab computers to program and operate the robots and CNC machine. The detail description of the laboratory equipment is available in the ASU engineering website[5]. Students work in a batch of 2 to 3 to complete about 8 experiments out of 12 developed so far that have been published as a supplementary textbook[6].

The following is a brief description of each of the equipment and an associated experiment along with the learning objective.

(a)   Lego-Mindstorm Programmable Robots:

Experiment: Assembling and programming a mission specific robot to accomplish the given task
Objective: To be able to translate physical tasks to computer codes in an icon driven programming language RoboLAB (version of LabVIEW)

These very popular and relatively inexpensive robots are created by snapping together conventional Lego blocks around a programmable RCX brick, which has its own microchip and operating systems. In its most basic version, the RCX uses sensors to take input from the environment, processes the data and signals up to three motors or lamps on or off in any one of five power levels.

Instruction set for a typical student project for "Car" robot is:

(i)   The car will go forward when the "Run" button is pressed.
(ii)   When the car hits an obstruction, which causes the bar in front to be pushed, it will go in reverse, the light in the back of the robot will be turned on and the wheel on the top will start turning.
(iii) While going in reverse, when the car crosses a dark line, it will stop, light will be turned off, wheel on top will stop turning and the first line of "Row Row Row your boat" will be played.
(iv)   If the bar in front of the car is pushed again, step (i) through (iii) will be repeated.

Students are expected to submit a lab report explaining how each task has been translated into computer codes taking into account the physical arrangement of the robot's components (wheels, arms, lights etc.) and data needed to activate them.

(b)   PC Turn 55 CNC lathe

Experiment: Developing CAD/CAM program and Machining a chess piece in a CNC machine

Objective: To be able to sketch in two dimensions from given coordinates using the menu commands of WinCAM software and develop an understanding of metal cutting machining process through numerical programming.

PC Turn 55 is a 2-axis PC-controlled CNC benchtop lathe with programmable tool turret that can accommodate up to 3 external and 3 internal turning, boring, threading or cutting-off tools. This lathe is capable of performing all of the classic lathe operations common to full-size machines. This machine is controlled by WinCAM software that is particularly suited for training students to get familiar with all aspects of CAD/CAM assisted NC programming within a very short period. WinCAM has three programming modes:

- CAD (computer aided design),
- CAM (computer aided manufacturing)
- NC (numerical controlled machining)

WinCAM helps create an on-screen graphic work piece in the CAD mode, then an NC program is generated in the CAM mode by means of various machining cycle. The NC program can be processed either directly to machine the part from stock or can be transmitted to a full size CNC industrial machine. The graphic simulation included in the WinCAM shows an exact copy of the machining process and is responsible for a better understanding of the programming sequence and for more safety during program creation.

Students are asked to machine a chess piece from the known coordinates of the profile from a one inch diameter ABS plastics stock. They first design the profile in the CAD mode, program the cutting tool path and associate speed and feed in the CAM mode and finally machine the part in the NC mode. WinCAM being an icon driven software, all the programming is done by clicking on appropriate icons instead of writing the program on a text based computer language.

(c)   FLOTEK 1440 Wind Tunnel

Experiment: Determination of lift characteristics including onset of stall on a NACA airfoil
Objective: To be able to understand nature of air flow over solid bodies specifically wing profile and pressure vs. velocity relationship as espoused by Bernoulli's Principle.

ASU's wind tunnel is a computer controlled subsonic tunnel with 12" x 12" x 36" test section that is fitted with a 20-tube manometer for enhanced visual reference and a two-component balance beam for measurement of drag and side force. Computer data acquisition system consists of 16 pressure transducers, 16 channels analog to digital and 2 channels digital to analog capability. LabVIEW software allows real time display of up to 16 readings of pressure and velocity over the test object while controlling the angle of attack and fan rpm.

In this experiment, students working in a team of 2 or 3 manually record the height of water columns from the manometer tubes connected to the pressure tapings on one of the NACA airfoils upper and lower surfaces. Then they insert this information in a preformatted spreadsheet to compute pressure distribution and the lift generated for one angle of attack per team. Combined results from the entire class, when plotted, demonstrate

the variation of lift coefficient as a function of angle of attack for the given airfoil. The plot also reveals the stall angle and the maximum overall lift attained. The short threads mounted on the upper surface of the airfoil (tufts), start vibrating as stall approaches as does the sudden drop of the water columns in the manometer tubes. Students get a visual reinforcement of the practical nature of fluid flow and a lesson in teamwork as their collective work is judged to evaluate the lift characteristic of the airfoil.

Cp Distribution on NACA 2415 Airfoil
(Angle of Attack = 9 deg)

Lift Co-eff. vs. Angle of Attack
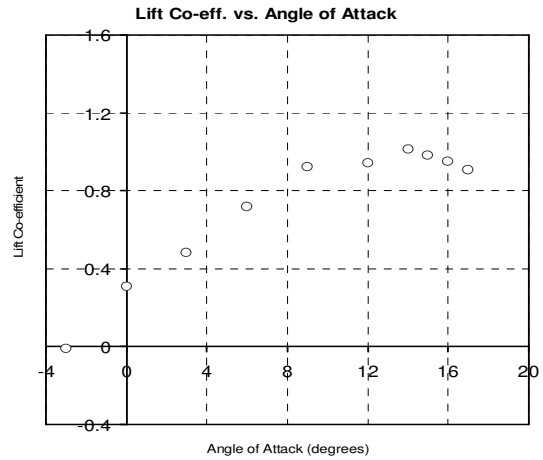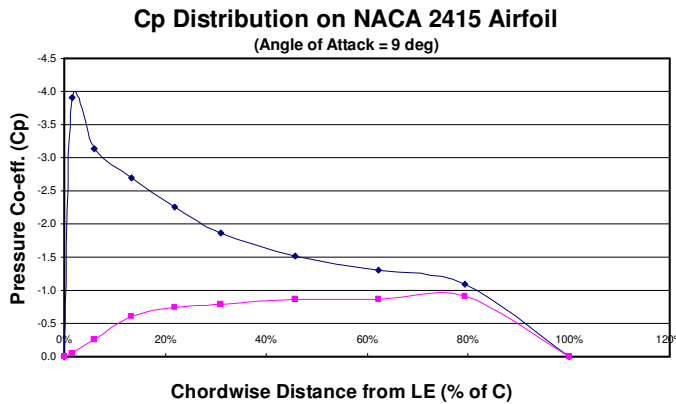
Experiment: Determination of drag characteristics of one object or multiple objects in close proximity – Stock Car experiment

Objective: To be able to appreciate that drag force increases as square of the velocity and the drag decreases due to the draft created by another object in front.

In this experiment students measure the drag and side force experienced by a stock car model in the tunnel by two component balance beam. The data were recorded by the LabVIEW program for different tunnel speed (fan rpm) and plotted.

Drag vs. Speed for a Stock Car Model
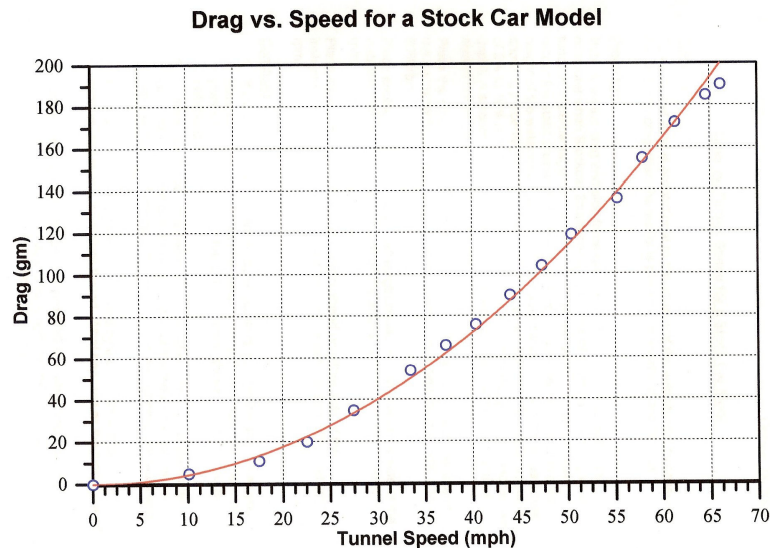
Students also learn that the drag decreases if another car is placed slightly ahead next to the test car due to the partial vacuum created by the wake of the car in front. This experiment provides a rational explanation of a familiar event.

(d)   SolidWorks software and Dimension 3D Printer

Experiment: Developing solid models in computer and making a 3D part
Objective: To be able to draw 2D sketch(s) from a drawing of a given solid object, then turning that into 3D model in the computer and subsequently making the part.

In this experiment of developing and making the candlestick, the body is an axisymmetric object obtained by revolving the given profile against the central axis and the handle is obtained by sweeping the elliptical profile along the given path. Students create the 2D sketch in SolidWorks by line and arc menu commands and dimensioning them accordingly. 3D solid is created by using revolve and sweep features. Students get a better feel in three dimensional spatial relationships from developing the solid model of this very recognizable object.

ASU's 3D Printer is a popular Rapid Prototyping machine based on Fused Deposition Modeling (FDM). Creating prototypes is an important part of the product development cycle. Prototypes enable form, fit, and function testing as well as an ergonomic evaluation and marketing tool. In the FDM process, plastic is heated and extruded through a small orifice to lay down material one layer at a time.
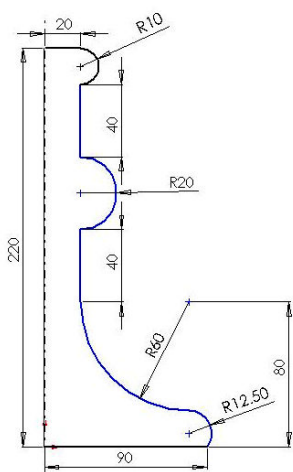
The CAD file created in SolidWorks is made available to the software called Catalyst in the STL format. STL file approximates the geometry in the CAD file by constructing a mesh of triangular elements (as few as possible) to represent the part accurately. The solid model

can be scaled and rotated about all the 3 axes. Once the processed STL file is submitted by Catalyst to the 3D printer, the solid model will be made automatically. Afterwards, cleaning from the support material and finishing has to be done manually.

This project exposes students to the process of designing, developing solid model in the computer and creating prototype that can be examined in closer detail to test fitting and functionality before initiation of large scale production.

(e) Axiovert inverted microscope and Tinius Olsen Universal Testing Machine

Experiment: Observing microstructure of metals and the effect of heat treatment.
Objective: To be able to develop an understanding of phase diagram and its effect on microstructure.

Students working in teams prepare metal samples by polishing the given specimen with various grades of sand papers, diamond paste, alumina suspension and etching with the recommended solution. The resulting microstructure is digitally captured in the color camera and compared before and after heat treatment. Students also conduct a hardness test in the Universal Testing Machine (UTM) before and after heat treatment to observe change in the hardness number. UTM is also used to demonstrate the traditional tensile test on various structural materials. These experiments are conducted in support of "Introduction to Engineering Materials", a 2000 level engineering course.

Present Course Structure and Students' Perception

The laboratory experiments have become a prominent part of the new course structure without sacrificing any of the materials covered in the original course. The three hour laboratory session is held once a week. Students work in groups of 2 to 3 and complete about 7 to 8 experiments in total: 1 in RoboLab, 2 in Wind Tunnel, 2 in CNC machine, 2 to 3 in SolidWorks. At the completion of each experiment they have to submit an individual lab report in order to get the credit for conducting that experiment. Because of the wide variation of the nature of each experiment, the reports are to some extent dependent on the equipment and the specific experiment. In general, the lab report is expected to contain title and objective of the experiment, brief description of the procedural steps followed, a flow chart or its equivalent if any programming is involved and how any problems are resolved if the desired result have not been obtained at the first attempt.

The course grade is currently based on following distribution:

Lab Projects	30%
Two Tests	20%
Home Work	20%
Final Exam	30%

The current format of the course include the following components: (a) lectures on various topics including career choice, requirement of different engineering majors, team work, design principles etc., (b) videos on different major engineering projects of modern times, (c) field trips

to engineering industries, (d) application oriented problem solving on basic and intermediate mathematics as well as Statics, Electrical Circuits etc. and (e) laboratory experiments.

During the fall 2006 semester, for the first time, students were asked to fill out a survey questionnaire in order to get a feedback about this new format of the course. The class consisted of only 10 students. There were 12 questions in all, 6 were about the course itself and 6 were on the lab experiments. Results from these questions were shown in the following table.

Table 1.   Responses from the survey questions from fall 2006 semester

Q 1)   **Which was most enjoyable part of the course?**

Responses	Frequency	Percentage
Lab Projects	5	50
Lectures	2	20
Videos	1	10
Field Trips	0	0
Problem Solving	1	10
(Missing)	1	10

Q 2)   **Did the course help you better understand what engineers do in real life?**

Responses	Frequency	Percentage
Yes	6	60
Somewhat	4	40
No	0	0

Q. 3)   **Did the knowledge and information gathered from this course matched your expectation of what engineers do?**

Responses	Frequency	Percentage
Yes	5	50
No	2	20
Not sure	3	30

Q. 4)   **Did the course help you choose an engineering major?**

Responses	Frequency	Percentage
Yes	3	30
No	1	10
Not exactly	6	60

Q. 5)   **Was adequate amount of material covered in each section?**

Responses	Frequency	Percentage
Yes	9	90
No	1	10

Q. 6)   **Will this course help you get better prepared for higher level courses?**

Responses	Frequency	Percentage
Yes	5	50
No	1	10
Do not know	4	40

Q. 7)   Which lab project was most exciting to you?

Responses	Frequency	Percentage
RoboLAB	5	50
CAD/CAM/NC Programming	3	30
Wind Tunnel	1	10
SolidWorks 3D modeling	1	10

Q. 8)   Has the exposure to different computer software helped improve your logical thinking ability?

Responses	Frequency	Percentage
Yes	10	100
No	0	0

Q. 9)   Which software was most challenging for you to understand?

Responses	Frequency	Percentage
RoboLAB	1	10
WinCAM	2	20
SolidWorks	4	40
Excel	0	0
PSI-PLOT	3	30

Q. 10)   Which project will you delete in order to devote more time to the remaining projects?

Responses	Frequency	Percentage
RoboLAB	2	20
CAD/CAM/NC Programming	1	10
SolidWorks	3	30
Wind Tunnel	4	40

Q. 11)   Did the lab manual helped you to understand the objective and procedural steps of the projects?

Responses	Frequency	Percentage
Yes	7	70
No	0	0
Somewhat	3	30

Q. 12)   Do you like to see the lab grade change from current 30% of overall grade to a different value?

Responses	Frequency	Percentage
Raise	6	60
Lower	0	0
Do not change	4	40

For overall comments, students also expressed an interest in seeing more videos on modern engineering projects; more field trips and lectures from visiting engineers. Only one student complained about too much material covered in the course and one asked for redistribution of grade such that final comprehensive exam will have only 20% weightage instead of current 30%.

Conclusion

It is clear from the feed back received from the students that they have enjoyed the lab experiments and recognize the relationship of the projects performed in the lab to the real world projects done by the practicing engineers. In that respect the integration of the lab experiments does fulfill the original intent of restructuring the course so that students gain an early exposure in the methods of arriving at a quick and accurate solution by using manufacturing and testing equipment by applying known information and transforming the data generated to provide the answer.

However, the current content of the course may be more than what can be handled by average student, specifically the varied nature of the lab equipment and software demands additional time and effort that is beyond the scope of a normal 3 credit hour course. It is the intent of this author to reevaluate the course content based on the students' response of the survey questionnaire. Because of the rigors of data collection and reduction to determine the lift characteristic of the NACA wing profile in the wind tunnel as well as requirement of collective effort of the entire class to obtain the desired result, it seems to be better done as a demonstration rather than actual experiment. Time saved may be utilized in more effective training in SolidWorks 3D solid modeling software. Also, the lab grade may be raised to 40% at the expense of the final examination grade which can be reduced to 20%, next time the course is taught. Though it is hard to guarantee beforehand, serious effort will be undertaken to arrange seminars by practicing engineers and more videos can be shown on contemporary engineering projects, viz., bioengineering or nanotechnology.

The Engineering Laboratory is also used to conduct outreach activity in the form of engineering workshops for middle and high school students throughout the year which satisfies the secondary objective of the Department of Education's grant to motivate the K-12 students to the rewards and challenges of the engineering career.

Acknowledgements

Bibliography

1. Masoom, F., and Masoom, A., "What to Introduce in Introduction to Engineering?", Proceedings of the 2002 ASEE Conference and Exhibition.
2. Lau, P., McNamara, S., Rogers, C., and Portsmore, M., "LEGO Robotics in Engineering", Proceedings of the 2001 ASEE Conference and Exhibition.
3. Maletsky, L., Hale, R., Sorem, R., and Ramirez, G., "Integrating Modern Design and Manufacturing Equipment into Engineering Curricula", National Science Foundation CCLI Adaptation and Implementation Award No. 0127081, December 2001.
4. Parker, P., and Anderson, M., "Creation of an Introductory Engineering Course Based on Sooner City", National Science Foundation CCLI Adaptation and Implementation Award No. 0127117, December 2001.
5. URL: http://www.asurams.edu/engineering/facilities.htm; Albany State University.
6. Sinha, A., "Engineering Laboratory Experiments", published by LAD Custom Publishers, July 2004.