AC 2011-2807: WHICH COMES FIRST THEORY OR EXPERIMENT?

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Which Comes First – Theory or Laboratory Experiment?

Abstract

The positive effects of laboratory exercise on engineering education are well recognized. To enhance student learning, many engineering technology courses include laboratory experiments. Traditionally, the students are introduced to the theories first. The lectures are then followed by laboratory activities. However, the timing of the laboratory sessions with respect to that of the lectures may influence student learning. In a reverse sequence, giving students opportunities to conduct experiments before presenting the theories may improve or impede learning.

This paper presents an effort in investigating the effects of lecture-laboratory timing on student learning. In a Fluid Power Technology course, a group of students were taught in the traditional “theory first” approach. Another group of students were assigned to conduct experiments before attending the lecture (the “experiment first” approach). It was found that there is no significant difference in student performance between the two groups. The same arrangement was made in a Non-Metallic Materials and a Strength of Materials courses. In addition to the regular assessment, surveys were conducted to inquire students’ learning style and their preference. Preliminary results showed that while most of the students are indifference, some students prefer a specific “theory first” or “experiment first” approach. It is believed that depending on the course type and the student learning style, learning could be affected by the teaching approach. Further study on the lecture-laboratory timing that could lead to an effective pedagogy is recommended.

Introduction

Laboratory exercises are an essential part of engineering technology education. In most of the mechanical and manufacturing engineering technology courses, hands-on labs are designed to help student to acquire the knowledge and skills taught in the class. Since positive effects of lab activities on student learning have been recognized, engineering and engineering technology professors continue to develop and incorporate laboratory exercises into various courses.

To introduce science and engineering to prospective students and to encourage early stage engineering students to continue with the upper level courses, freshman level laboratories were developed for students to operate equipment and conduct experiements.[1-3] In manufacturing courses, at both undergraduate and graduate levels, hands-on practical manufacturing projects were implemented to promote active learning. The labs involved include rapid prototyping, laser machining, book-making, and welding, etc.[4-6] Material testing was conducted in labs to provide the fundamental material science knowledge necessary to perform engineering design and material selection. [7,8] A number of innovative experiments on thermodynamics, heat transfer, and fluid mechanics were developed to support student learning of important concepts and theories.[9-13] In projects funded by NSF, the use of “everyday devices” and “living laboratory” to help teach core concepts in the thermal and fluid sciences was reported.[14,15] The approach (giving real life examples) was used in a solid mechanics course without active experiments.[16] In dynamics and vibration courses, laboratory exercises were designed to teach the instrumentation knowledge and skills.[17,18] Beams with two different geometries were used in experiments and the results were compared to that of finite element stress analyses.[19] A number of “design-build-test” examples for students to learn the theories and skills through hands-on laboratory activities were reported.[20-24]

In the courses with lab components, students are typically introduced to the theories before performing lab experiments. However, this sequence is not always attainable due to scheduling constraints. That is, students enrolled in certain sections could conduct lab experiments before the lectures later in the week. In scientific discoveries, the relativity and black hole theories were proposed before experimental validation, while the gravitation and many of Edison’s inventions started from observations and experimentations. Little information is available regarding the outcome of “theory first” vs. “experiment first” approach on the acquisition and retention of knowledge and skills. Therefore, the question to be addressed is: “Does the lecture-lab sequence affect student learning?”

In this paper, the authors present an effort in investigating the effects of lecture-laboratory timing on student learning. Students were enrolled in either “lecture first” sections or “lab first” sections in three different engineering technology and industrial distribution courses. The semester grades were calculated and student survey were conducted to evaluate student learning. In the next sections, the course contents and assessment methods are described and the results and discussion are shown. The paper ends with a summary on the lessons learned from this study.

Course and Laboratory Descriptions

Student learning in three courses offered by the Department of ___ at ___ University was studied. The course can be considered as a “knowledge” course where new information is introduced and memorization is needed, a “skill” course that concept, theory, and problem solving are emphasized, or a balanced combination of the two. For each course, students attended the lectures at the same time (e.g., on Tuesdays). However, due to scheduling constraints some students attended labs prior to the lectures (e.g., on Mondays) while others had lab exercises after lectures (e.g. on Wednesdays). The course contents and the lab activities are described below.

Fluid Power Technology

Course Description: Detailed overview of the engineering concepts of hydraulic and pneumatic power and its components within a system to provide transmission of that power into useful work; experimental application of the related theory as it relates to the industrial distributor. All theory taught is linked to the "real world" for application in industry.

Course Objective: To prepare the Industrial Distribution student for a career in the industry of Fluid Power Technology. This is accomplished through the interaction of both theory and laboratory "hands on" exercises using real world components and systems related to the Fluid Power industry.

The course is designed for the students in the Industrial Distribution program at _ University. Tables 1 and 2 show the topics covered in the lectures and the laboratory activities to be performed by the students, respectively. A pneumatic trainer used in the laboratory is shown in Fig. 1. It can be observed that a balanced combination of knowledge and skills are taught in the course. The student grades are based on two midterm examines (20% each), quiz/home work (5%), project (10%), laboratory assignment (20%), and final examine (25%).

Table 1. Topics covered in the Fluid Power Technology course

	Lecture Topics
1	Introduction to fluid power, fluid transfer, fluid power symbols
2	Physical properties of hydraulic fluids (density, specific gravity, viscosity)
3	Fluid power concepts, pressure, pressure dead, Pascal’s Law
4	Continuity equation, flow rate and velocity
5	Hydraulic energy, hydraulic horsepower (HHP)
6	Pumps and pumping theory, cavitation, displacement
7	Valves, directional, pressure & flow, cartridge, proportional
8	Filtering, standard contamination control
9	Fluid power reservoirs & actuators, conductors & accumulators
10	Pumps, Non-pos. displacement, pump selection
11	Pneumatic theory, drying, filtering, lubricating, compressors, actuators
12	Fluid transfer valves
13	Safety in hydraulics

Table 2. Laboratory exercise for the Fluid Power Technology course[25]

	Lab Topics
Lab 1	Fluid power basics
Lab 2	Basic hydraulic & pneumatic components and circuits
Lab 3	Pumps and introduction to hydraulic circuits
Lab 4	Hydraulic circuits: regeneration & synchronization
Lab 5	Hydraulics, meter in and meter out
Lab 6	Advanced hydraulics
Lab 7	Pneumatics - I (Pneumatic Trainer, Circuits)
Lab 8	Pneumatics - II (Developing Pneumatic Circuits)
Lab 9	Pneumatics - III (Control of Pneumatic Systems)
Lab 10	Accumulator
Lab 11	Introduction to thermodynamics - I (Refrigeration Cycle)
Lab 12	Introduction to thermodynamics - II (HVAC)

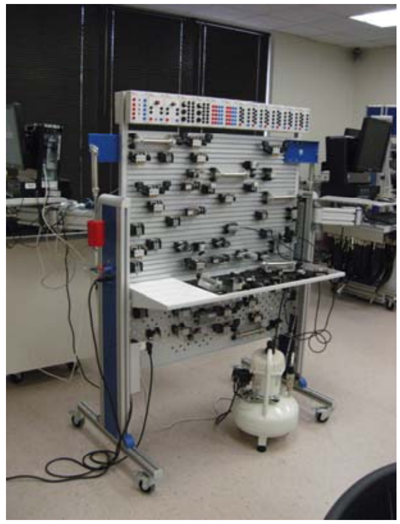

Figure 1. A pnumerical trainer used in the Fluid Power Technology laboratory[25]

Non-metallic Materials

Course Description: Introduction to structure, properties, processing and application of forest products, plastics, ceramics and composites; laboratory includes processing, physical and mechanical testing, applications, surface treatment and material identification.

Course Objectives: To become familiar with common non-metallic materials including polymers, composites, and ceramics, and their properties, manufacturing processes, and typical applications.

Table 3. Class lecture topics in the non-metallic materials course

	Class Lecture Topics
1	Introduction, materials and environment
2	Mechanical, thermal, and magnetic properties of materials
3	Inter-atomic bonding, crystal structure, crystal defects
4	Introduction of polymers – monomers
5	CES EduPack software
6	Polymerization, polymer classification, synthetic fibers
7	Plastics – commodity and engineering polymer, foam, barrier property
8	Manufacturing processes for plastics
9	Elastomers
10	Introduction of composites
11	Manufacturing processes for composites, applications of composites
12	Introduction of ceramics, manufacturing processes for ceramics
13	Advanced ceramics, types and properties of glass, applications of Ceramics
14	Liquid Crystal and LCD
15	Semiconductors: LED, Solar Cell

The course is offer to both Engineering Technology and Industrial Distribution students. The class lecture topics and hands-on laboratory activities and experiments are listed in Tables 3 and 4, respectively. The course can be considered as a "knowledge course" as students are constantly introduced to new (to most of the students) information. The student grades are based on two major examines (20% each), attendance (5%), lab practical, lab report, quiz, and homework assignment (30%), and final examine (25%). In this study, the students enrolled in the Non-metallic Materials course were also given a questionnaire to survey students' learning style and lecture-lab timing preference. The survey questions and results are discussed in a later section.

Table 4. List of laboratory assignments for the Non-metallic Materials course[8]

	Lab Topics
Lab 1	ISO & ASTM Standards, CES EduPack - Getting Started
Lab 2	Tensile Testing of Plastics, Video: Crude (Modern Marvel), Plastic Blow Molding (SME)
Lab 3	Impact & Hardness Testing of Plastics
Lab 4	Chemical & Thermal Properties of Plastics, Hands-on Observation of Plastic Components; Video: Plastic Injection Molding (SME)
Lab 5	Plastics Manufacturing Processes (Compression Molding, Injection Molding, Thermal Forming), Video: Compression Molding, Thermoforming (SME)
Lab 6	Making Composite Laminate, Hands-on Observation of Composite Components, Video: Manual Composite Layup & Spray up (SME)
Lab 7	Tensile Testing of Composite Laminate, Video: Carbon (Modern Marvel), Composite Materials (SME)
Lab 8a	Lab #8a Making a Ceramic Mug Using Slip Casting Method
Lab 8b	Lab #8b Trimming of Dried Green Ceramic Mug
Lab 8c	Lab #8c Adding Glaze to Coffee Mug
Lab 9	Lab #9 Adding _ Seal to Coffee Mug (Decal Process), Hands-on observation of Ceramic Components, Video: Filament Winding, Pultrusion (SME)

Strength of Materials

Course Descriptions: Stress and strain; elastic moduli, Poisson's ratio; torsion, bending; design of beams and shafts; stress transformation; material and strength characterization laboratory tests.

Course Objectives: To prepare students with the fundamental principles and problem solving skills for stress analysis and design of structural and machine members.

The course is offered to the Manufacturing and Mechanical Engineering Technology students. It is a prerequisite for the subsequent Mechanical Design Application courses. The course contents and lab topics are listed in Figures 5 and 6, respectively. Fig. 2 shows an apparatus for torsion experiment conducted in the lab. The course is considered a "skill" course since students are required to understand various concepts and theories. Students are also tested for their problem solving skills in stress analysis. The grading is based on two mid-term examines (20% each), lab practical and report (15%), homework assignment (10%), quiz and attendance (10%), and the final examine (25%). Similar to the Non-metallic Materials course, a survey was conducted and the results will be discussed in the next section.

Table 5. List of topics covered in the Strength of Materials course

	Lecture Topics
1	Introduction, Review of Statics
2	Stress, Strain
3	Mechanical Properties of Materials
4	Axial Load
5	Torsion
6	Bending
7	Transverse Shear
8	Combine Loading
9	Stress Transformation
10	Mechanics of Material Application, Review

Table 6. Lab exercises in the Strength of Material course

	Lab Exercises
Lab 1	Installation of Strain Gauges (cantilever beam)
Lab 2	Installation of Strain Gauges (pressure vessel / beverage can)
Lab 3	Uniaxial Tensile Test
Lab 4	Uniaxial Tensile Test for Anisotropic Materials
Lab 5	Torsion Test
Lab 6	Determination of Modulus of Elasticity and Poisson's Ratio
Lab 7	Stress Concentration
Lab 8	3–Point Bending Test
Lab 9	Principal Stresses and Strains
Lab 10	Combined Bending & Torsion Test
Lab 11	Thin-Walled Pressure Vessels

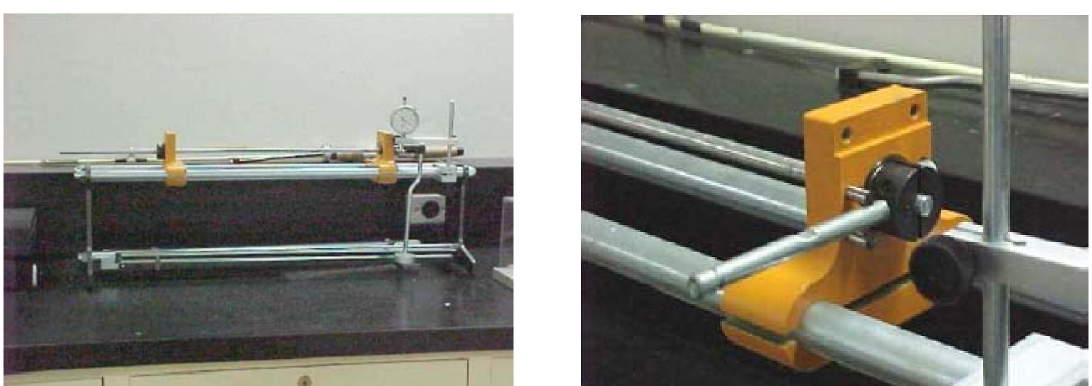

Figure 2. A "twisting and bending" tester used for torsion experiments[26]

Evaluations of Student Learning

Student performance was evaluated based on the final grades. Students grades in "lab first" sections and "lecture first" sections were calculated separately. Table 7 shows the average grades for each section in the Fluid Power Technology course for 4 years (eight semesters). The grade is shown in points based on the maximum total of 500 pints. The number of students and the standard deviation of the grades within the section are also provided. It can be observed that while the average grades for the "lecture first" sections seem to be slightly higher, the difference is insignificant considering the standard deviations.

Table 7. Student performance in "lab first" and "lecture first" sections in the Fluid Power Technology course

	Spring Semester				Fall Semester			
	Lect-lab Timing	# of Students	Grade Points	Standard Deviation	Lect-lab Timing	# of Students	Grade Points	Standard Deviation
2009	Lab first	17	429	18	Lab first	15	433	20
		14	425	30		19	422	29
	Lect first	16	433	31	Lect first	19	428	21
		10	440	16		15	420	25
		5	450	27		13	433	22
						14	418	30
2008	Lab first	20	421	18	Lab first	14	404	18
		13	427	24		19	434	19
	Lect first	19	417	20	Lect first	18	416	23
		10	432	19		11	425	19
						4	427	19
						16	420	18
2007	Lab first	16	423	21	Lab first	16	419	21
		16	434	22		13	419	25
	Lect first	16	434	20	Lect first	17	409	24
		16	432	22		13	417	19
		12	449	25		14	441	23
		17	425	28		12	437	12
2006	Lab first	18	412	18	Lab first	16	436	27
		15	414	29		12	429	20
	Lect first	11	421	24	Lect first	13	424	24
		17	407	18		12	414	34
		14	413	38		15	428	26
						14	411	21

Table 8 shows the student performance in the Non-metallic Materials course. The grade is shown in points based on the maximum total of 1000 points. The data are available for one semester only. It can be observed that the students enrolled in the “lab first” sections performed slightly better (~2.3%) than those enrolled in “lecture first” sections. However, the difference is not significant when standard deviation is taken into consideration.

Table 8. Student performance in “lab first” and “lecture first” sections in the Non-metallic Materials course

	Number of Students	Grade Points	Standard Deviation
Lab first	16	812	72
	14	804	48
	17	811	65
	14	736	64
Lecture first	10	742	94
	17	795	62
	12	767	82
	12	758	63

Similarly, the student grades in the Strength of Materials for three semesters are shown in Table 9. The grade is based on the maximum total of 100 points. The average grades of the “lecture first” sections are consistently better than that of the “lab first” sections. Again, with the shown standard deviation, the difference is not significant.

Table 9. . Student performance in “lab first” and “lecture first” sections in the Strength of Materials course

	Lect-lab Timing	# of Students	Grade	Standard Deviation
Fall 2010	Lab first	18	72	13
	Lecture first	18	75	12
		10	74	14
Spring 2010	Lab first	18	72	13
	Lecture first	18	75	12
Fall 2009	Lab first	19	74	9
	Lecture first	17	78	8

Since the type of course (“knowledge” vs. “skill”) and students’ preference of lecture-lab timing were not considered, efforts were made to conduct student survey in the Non-metallic Material and Strength of Material courses. The survey questionnaire requested students to identify their learning styles and lecture-lab timing preference, among other questions related to course contents and lecture delivery methods. The questions relevant to this study include:

Q 1) I am a “learning by thinking” person (logic analysis).
Q 2) I am a “learning by feeling” person (personal involvement and/or past experience).
Q 3) I am a “learning by doing” person (active experimentation and hands-on).

Q 4) I am a “learning by watching and listening” person (observations).
Q 5) I need to know the physical evidence and/or numbers that back up a concept. I pay attention to details in lab procedures and I am a quantitative person.
Q 6) Knowing the big picture or concept is all I care about. I don’t care too much about the details in lab procedures.
Q 7) I believe I can learn the class materials well without taking the labs.
Q 8) Having lab exercise before lecture can help me better understand principles when taught.
Q 9) Having lab exercise after lecture can help me better understand experimental results.
Q 10) All things considered, I prefer to have lab before lecture.
Q 11) All things considered, I prefer to have lecture before lab.
Q 12) I am fine with either “lab first” or “lecture first” arrangement.

The first four questions are used to identify the students’ learning styles. Questions 5 to 9 evaluate students’ attitude towards laboratory exercises. The last three questions survey students’ “lecture-first” versus “lab first” preference. The results of student survey from Non-metallic Materials (one semester) and Strength of Materials (two semesters) are shown in Table 10. The percentage of students answered “agree” or “strongly agree” to the questions are calculated.

Table 10. Survey of student learning style, attitude towards lab, and preference of lecture-lab timing

	Non-Material Materials	Strength of Materials
Q1	73%	63%
Q2	61%	68%
Q3	97%	97%
Q4	67%	57%
Q5	69%	61%
Q6	38%	33%
Q7	30%	72%
Q8	55%	28%
Q9	66%	64%
Q10	27%	9%
Q11	54%	48%
Q12	57%*	42%

* The percentage is derived from students answered “neutral” in *Q10* and *Q11*.

It can be observed from the first four questions that the students generally can have various approaches to acquire knowledge and skills taught. However, the majority of the students (97%) identify themselves as a hands-on learner, which is typical for engineering technology students. This is also reflected in the response to Q6. The data indicate that students are interested in having concepts reinforced by experimentation. Majority of the students in Non-metallic Materials course believe that lab exercise can contribute to their learning of the class material, while many students in the Strength of Materials course did not feel their learning experience is enhanced by lab activities (Q7) As the two courses surveyed are different in nature (knowledge vs skill), the student response can be used to redesign Strength of Material lab activities in the future.

From the results of Q8 and Q9, it is found that the advantages of "lab first" and "lecture first" are both acknowledged by the students. While the students in Non-metallic course showed preference to have a "lecture first" approach, the students had no strong opinion on the lecture-lab timing. On the other hand, the students in the Strength of Materials course expressed a significantly strong preference to having theories introduced before conducting experiments. This could be due to the fact that theories taught in that course are abstract concepts that required explanations by the instructor during lectures.

Lesson Learned

This paper presents the results of a preliminary study on the "theories first" versus "experiment first" approaches used in three engineering technology courses. It was found that in a "knowledge" type course such as Non-metallic Materials, students enrolled in "lab first" sections have a slightly higher average grade. On the other hand, in a "skill" course where concepts and problem solving is emphasized, the students enrolled in the "lecture first" sections often performed better. The difference, however, is insignificant. Student surveys were conducted. It was found that students strongly prefer a "lecture first" approach in the Strength of Materials course. As there are many factors that could influence student learning, a more in-depth investigation involving student learning style, course type, lab activities design, and lecture-lab timing is suggested.

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