The Integrated Systems Engineering Laboratory – An Innovative Approach to Vertical Integration using Modern Instrumentation

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Abstract

The current paradigm in engineering course instruction builds on a lecture prerequisite structure but ignores the need for a laboratory prerequisite structure. Educational quality is therefore diminished as instructors optimize specific laboratories but fail to optimize the overall program laboratory experience. This paper presents a learning environment based on modern instrumentation that forces students to use not only concepts and skills acquired from the lecture, but also actual data and models acquired from lower division laboratories, in upper division laboratories. The vertical integration occurs because students must utilize their previous laboratory work as a reference and/or building blocks as they study the different facets of the same experimental set-ups in multiple engineering laboratories. The students learn to appreciate the integrated nature of modern systems since they get to use the same set-ups in multiple courses. Set-ups such as the inverted pendulum, mobile robot, a model airplane, a model train and a wind tunnel make heavy use of data-acquisition systems, programs written and developed in LabVIEW and MATLAB, and modern communication protocols such as RS485. The entire interface is through virtual instrumentation, and the lab is also being given the capability of remote access to the students. There are other indirect advantages of this approach in terms of financial economy and faculty professional development. This project has been funded by the National Science Foundation (NSF) and has resulted in the development of the *Integrated Systems Engineering Laboratory* (ISEL) that houses vertically integrated laboratory exercises for twelve courses from three different curricula.

1. Introduction

Most universities have limited resources in terms of space and equipment, hence the development of new laboratories is always a challenge. Hence, when a need was identified at Lake Superior State University (LSSU) for a series of new courses and accompanying laboratories, an innovative solution was sought. This led to the development of a single multipurpose laboratory that will be used in multiple courses similar to the Interdisciplinary Intelligent Mechatronics Laboratory at the Georgia Institute of Technology [1]. The laboratory at Georgia Tech. is used by nine courses, but is limited to upper division and graduate courses. Further, there is no provision for a sequence of courses to set up a prerequisite structure in the course laboratory exercises. There are several other innovative approaches that have been reported in the engineering education literature. These approaches successfully use interdisciplinary courses [2, 3], multidisciplinary teams [4] and even an innovative *Learning Factory* that emphasizes the interdependence of manufacturing and design in a business environment [5]. This article proposes a novel approach to the shared laboratory experience that uses interdisciplinary courses and multidisciplinary teams to link the course laboratories in a logical sequence that enhances student learning [6, 7].

It was this line of thought that led some of the faculty members at Lake State to realize a deeper problem that exists in the academic environment, and that is a lack of a prerequisite structure in the different course laboratories similar to the prerequisite structure that exists in different courses. For example, students typically complete laboratory exercises in statics, dynamics, machine design, vibrations, controls, etc. without realizing that they all contribute to the development of truly integrated systems used in the modern industrial environment. This kind of a learning environment is termed as an isolated learning environment as shown in Figure 1. Some basic concepts are carried from lower division labs to upper division labs, but no real physical connection is provided. In this model, the laboratories are designed to reinforce basic concepts but have no larger purpose in the curriculum such as logically connecting to lab work completed in earlier or future courses. Advanced courses and laboratories assume students have mastered the basic theoretical skills, but no previous laboratory knowledge is required. Since laboratory time is short and new concepts must be emphasized, instructors are forced to use oversimplified set-ups. Further, a lot of existing laboratory facilities have not kept pace with new innovations in modern instrumentation. Finally, research and senior projects typically require equipment and other resources that may have little relevance to the undergraduate curriculum. All these shortcomings of the isolated learning environment can be overcome through implementation of an integrated learning environment which is described in the next section.

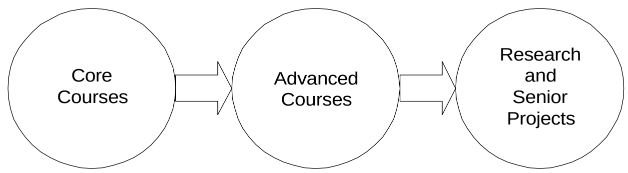


Figure 1: Isolated Learning Environment

2. The Proposed Integrated Learning Environment

The authors have proposed the development of an integrated learning environment that not only includes a logical prerequisite structure for the course lectures but also for the course laboratories. This integrated learning environment builds upon the course and laboratory work completed in core courses, advanced courses, and activities such as senior projects and undergraduate research. This approach to an integrated learning environment in courses as well as their laboratories is shown in Figure 2.

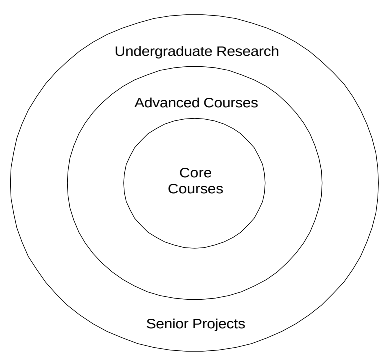


Figure 2: Integrated Learning Environment

Here, the laboratories in the integrated learning environment do have a larger purpose in the curriculum. Students study the basic concepts of complicated systems and it is hoped that this will pique their interest. When students enter the advanced courses and laboratories they will have mastered the basic theoretical skills and will have previous laboratory knowledge. Set-ups for the advanced courses do not need to be oversimplified because students have some familiarity with them from previous course work. They can pick up where they left off in their core courses and continue to study the systems from different points of view and for different reasons. These systems will be state-of-the-art, hence students involved in research and senior projects will be able to utilize the equipment in their work. The most important factor in the laboratory is the emphasis on modern instrumentation. The entire interface is through virtual instrumentation developed using software programs such as LabVIEW and MATLAB.

Typically, laboratory instruction suffers from isolated learning which results from a focus on short term solutions instead of long range goals. The integrated learning environment approach redefines the way laboratory instruction is designed. The integrated approach enables instructors to focus on long term goals while developing laboratory materials because the same multipurpose equipment set-ups are used for part or all of the laboratory instruction in sequential courses. This approach is demonstrated in Figure 3.

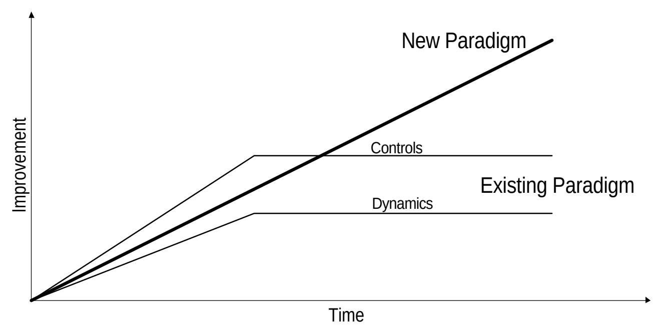


Figure 3: The Paradigm Shift

The vertical or y-axis represents improvement in: (1) student learning, (2) faculty professional development, (3) meaningful laboratory exercises, and (4) a true integrated learning experience. The rate of improvement (in terms 7of student and faculty motivation) in laboratory exercises levels off after an initial growth in the Isolated Learning Model (Existing Paradigm) as the instructor gradually exhausts ideas for new exercises and tends to rely on reusing previous exercises. The integrated learning environment (New Paradigm) forces the students and faculty to be extremely motivated. The student is forced to review and understand concepts and specific calculations from a prior course laboratory, since they have to apply that knowledge in future course laboratories. The faculty members are encouraged to continuously upgrade their laboratory exercises and constantly keep in touch with other faculty members who are teaching other course laboratories within this integrated environment.

3. ISEL – The Concept of Vertical Integration

The new laboratory facility called the *Integrated Systems Engineering Laboratory* (ISEL) will be used by multiple courses. Students in each of the courses will use the same six set-ups, or stations, but study different facets of it. A well defined plan was used to select the different pieces of equipment.

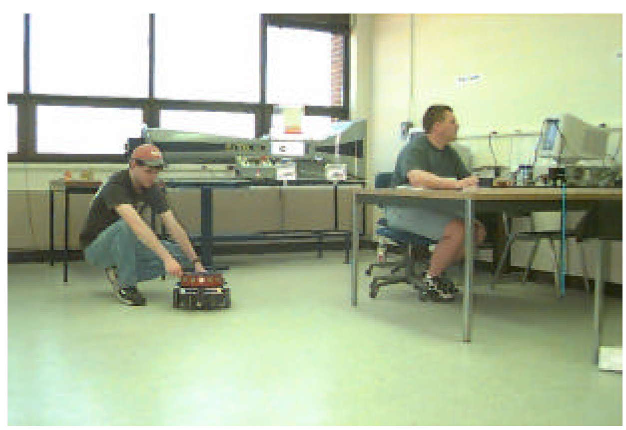
All the stations had to satisfy the following criteria:

a) They had to be integrated systems, i.e. they had to have mechanical, electrical, electronic, and computer programming components.
b) They had to be such that they could easily be assimilated in courses from Mechanical, Electrical and Computer Engineering.
c) They had to be such that they could give rise to laboratory exercises that could build upon each other in different courses.
d) Finally, they had to be fun pieces of equipment that would entice the students, and want them to come back and learn more about the equipment.

As an example of an integrated system being used to weave a prerequisite structure, an **inverted pendulum** set-up was selected. This has a rod balanced on a platform that moves in the horizontal plane. The aim is to move the platform using sensory feedback so as to automatically balance the rod vertically. It is similar to a person trying to balance a stick vertically on the end of one's finger by moving the hand around.

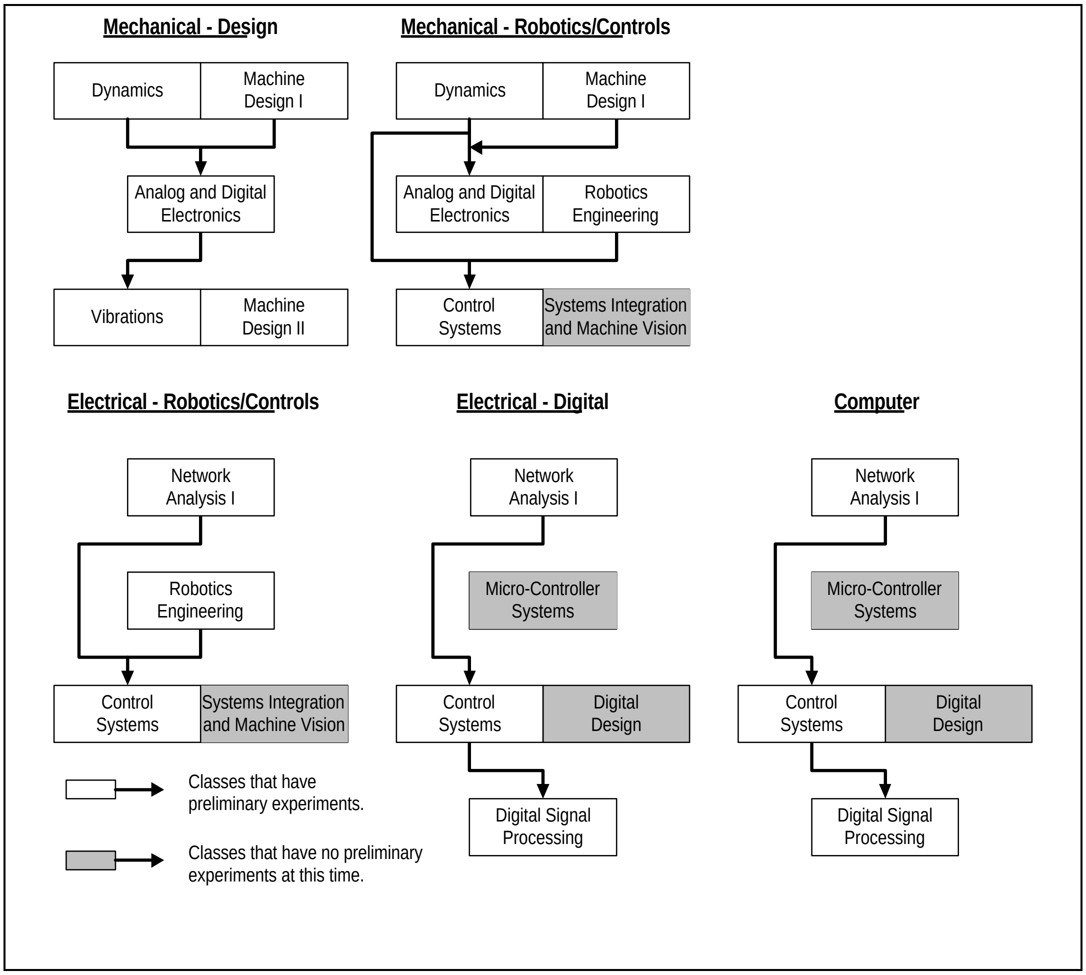
The following is an example of students studying the different facets of the inverted pendulum in the mechanical engineering curriculum:

Year	**Semester**	**Course**	**Laboratory Exercise**
Junior (3rd)	First	Dynamics	The system mathematical model, and its verification
	Second	Machine Design	The design of the physical model and selection of the components
Senior (4th)	First	Analog and Digital Electronics	Sensors and data-acquisition principles
	Second	Automatic Control or Vibrations (Depends on the option selected by the students)	Controls: Different control strategies and the effects of changing parameters Vibrations: The effect of vibrations and perturbations



One of the key components of all the lab exercises is that each successive laboratory in a higher level course builds upon the work done in the laboratories of the previous courses. For example, the students will be required to use the mathematical model of the pendulum, developed in dynamics, to design the physical system in machine design. Similarly, the information acquired and learned in dynamics and machine design will be used in the courses that complete the sequence shown above.

The School of Engineering and Technology at LSSU offers multiple options in Mechanical, Electrical and Computer Engineering programs. The ISEL has been developed to specifically target the Design and Robotics/Controls options in Mechanical Engineering, the Digital and Robotics/Controls options in Electrical Engineering and the general Computer Engineering program. The courses that will use the inverted pendulum to create the prerequisite structure in the different options are shown below:



The arrows show the progression of the students through the different courses. This diagram is only for the use of the inverted pendulum, hence courses that do not use this piece of equipment are shaded. There are five other pieces of equipment, all integrated systems similar to the inverted pendulum, that have corresponding diagrams.

4. Specialized Equipment Selected

Five additional set-ups, similar in concept to the inverted pendulum and representing truly integrated systems, allow for multiple courses to have the same physical laboratory set-up.

The **mobile robot** is a microprocessor based unit that has multiple sensors. The wheels are connected to stepper motors that drive the robot. There is a wireless modem that uses RS232 serial communication. This robot can be used in courses such as dynamics, microprocessors, controls and digital signal processing.

The **ball and plate unit** is an apparatus in which the objective is to control the position of a ball that is free to roll on a plate by using real-time feedback from a camera. The unit consists of a plate that is pivoted at its center point such that the slope of the plate can be manipulated in two perpendicular directions. This apparatus can be used in courses such as dynamics, machine design, vibrations, controls, machine vision and digital signal processing.

The **model train unit** consists of a train set that is computer controlled using wheel decoders. The communication is done through RS485 serial communication and further data on the kinematics is collected using external sensors and a data acquisition system. This unit can be used in dynamics, microprocessors, machine design, vibrations, controls and digital signal processing.

The **model plane unit** consists of sensors (strain gauges and accelerometers) mounted on the plane wings so as to study vibration phenomena such as free and damped oscillators, rotating unbalance effects, vibration isolation, impulse excitation and modal analysis. This unit can be used in courses such as dynamics, machine design, controls, vibrations and digital signal processing.

The **wind tunnel** is an apparatus that consists of a fan that blows air through a section of a specially designed conduit. The conduit has a test area for object placement and is equipped with several sensors for data-acquisition. The objective is to observe the effects of air flow on different types of objects (e.g. models of cars, buildings, planes, etc.). The wind tunnel will be used for courses such as dynamics, thermodynamics, fluid mechanics, heat transfer, controls and digital signal processing.

Four out of the six set-ups were bought from commercial vendors. These are the inverted pendulum, mobile robot, ball and plate apparatus and the wind tunnel. The model train and the model plane set-ups were developed in-house though the components were still obtained from commercial vendors. All the set-ups are rich test-beds for independent studies and research projects for students and faculty. Even though the intent of the project was to create a vertically integrated environment, the equipment can still be used for individual courses that may not fall within the scope of the vertical integration. Examples of these are courses such as machine vision, fluid mechanics, etc. Another noteworthy feature of this project has been the instant appeal to faculty in other departments. The wind tunnel has already been used by a faculty member in the Physics department and there have been requests for other equipment as well from a variety of other departments all over the University.

The table given below shows the equipment usage in the twelve different courses that have been targeted for vertical integration. The sequence of "X"s in any column show the prerequisite structure developed for that particular equipment within any curriculum.

	Inverted Pendulum	Mobile Robot	Ball & Plate	Wind Tunnel	Vibrations Setup	Train Setup
Computer Engineering						
EE310 Network Analysis	X	X			X	X
EE355 Micro-Controller Systems		X				X
RS460 Automatic Controls	X	X	X	X	X	
EE420 Digital Design		X				X
EE425 Digital Signal Processing	X	X	X	X	X	
Mechanical Engineering						
EE320 Dynamics I	X	X	X	X	X	X
ME350 Machine Design I	X			X	X	
RS385 Robotics Engineering	X	X	X			
EE305 Analog and Digital Electronics	X	X		X	X	X
ME425 Vibrations	X		X	X		X
ME455 Machine Design II	X	X			X	
RS460 Automatic Controls	X	X	X	X		
RS430 Systems Integration and Machine Vision		X	X			X
Electrical Engineering						
EE310 Network Analysis I	X	X			X	X
EE355 Micro-Controller Systems		X				X
RS460 Automatic Controls	X	X	X	X	X	
EE420 Digital Design		X				X
EE425 Digital Signal Processing	X	X	X	X	X	
RS385 Robotics Engineering	X	X	X			
RS430 Systems integration and Machine Vision		X	X			X

5. Impact Of The ISEL

The new facility is anticipated to have tremendous impact on the students and faculty in the School of Engineering and Technology at LSSU. It is envisioned that students who would have completed all the courses in the sequences described above would have a greater understanding of modern integrated systems and modern instrumentation. The faculty will work closely together to create new and meaningful laboratory exercises that logically connect different courses. It has already been used on an experimental basis in selected courses, and the student response has been tremendous. All the students are foremost struck by the fact that they get to play with exciting equipment and are not rushed to learn everything about that equipment in a couple of laboratory sessions. The idea of building upon their knowledge of the equipment in successive classes is definitely an important issue for them. It is further anticipated that this laboratory facility will become a model for other schools and universities.

6. Summary

The focus of this paper is the development of an innovative multipurpose laboratory that emphasizes vertical integration within multiple engineering curricula. The truly innovative aspect of the proposed laboratory environment is that students use the same experimental set-ups in multiple courses, and build upon not only the work done in the previous laboratories of the same course, but also those of previous courses. This leads to a definite prerequisite structure for the laboratory component of the courses similar to the courses themselves. Further, this approach is conducive to financial economy, faculty professional development, and encourages faculty members to work together to create meaningful experiments for students. Future work entails the use of the Internet to give access capability to students for using the equipment from remote sites. This would help in distance leaning courses for off-campus students that require laboratory experience as well as extended usage time for on-campus students.

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