

# Vertical And Horizontal Integration Of Laboratory Curricula And Course Projects Across The Electronic Engineering Technology Program

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## ABSTRACT

*This paper discusses the details of the curricular development effort with a focus on the vertical and horizontal integration of laboratory curricula and course projects within the Electronic Engineering Technology (EET) program at Texas A&M University. Both software and hardware aspects are addressed. A common set of software tools are introduced to the sophomore students in the EET curriculum; these tools are then used in several junior and senior level courses. Through early and repeated exposure to these tools, students learn to use them more effectively to solve various engineering problems in laboratory and course projects. A DC permanent magnetic motor is identified as one of the common hardware platforms for multiple course projects. By using a common platform for different course projects, the students can spend much less time preparing for the course projects. With each course adding different features to the common platform, the learning experience in several courses becomes seamlessly integrated. Surveys were conducted to show that the curriculum development effort improved the efficiency of student learning and enhanced the students' educational experience.*

**Keywords:** Curriculum Integration; DC Motor; Modeling and Simulation; Engineering Education

## INTRODUCTION

One of the emphases for undergraduate Engineering Technology (ET) education is hands-on experiences gained through laboratory classes and course projects. Almost every junior and senior level course in the Electronics Engineering Technology (EET) and Telecommunications Engineering Technology (TET) programs at Texas A&M University has a course project. Thus, the curriculum is packed with laboratory assignments and projects, each demanding the students' time. During the past several years, many students have made complaints about the work load they have been assigned in various courses. Some students even tried to come up with strategies to ease the work load, such as forming the same team for several course projects with certain team members working on one project only. Such efforts defeat the sole purpose of teamwork, can potentially hurt students' motivation for learning, have a negative impact on future student recruitment, and create too much pressure for students, all of which can lead to other serious problems. On the other hand, reducing the contents of the laboratory and course projects is not the best solution to this problem since most of the faculty members involved felt that they assigned the students what was necessary in order for the students to achieve the desired learning outcomes in their courses. Faced with this problem, a curriculum development effort has been started by several faculty members within the EET/TET programs. This paper discusses possible solutions to this problem. A combination of several educational research results was adopted in a unique way to address the problem faced by the Engineering Technology programs. Specific steps for implementing the pedagogy are discussed.

## **RESEARCH QUESTION AND METHODOLOGY**

Since reducing the contents and curriculum for the courses is not an option, it seems that the only viable solution to the problem faced by the EET/TET programs is to improve the efficiency of student learning. This leads the authors to study the following general research question:

### **How To Improve The Efficiency Of Student Learning In Laboratory Classes And Course Projects In An ET Program?**

How to improve the efficiency of student learning in general is one of the major topics in educational research. There are countless results that can be applied in principle. However, it is not easy to find specific implementation guidelines for ET. The existing educational research results must be modified so that they are effective for ET programs and ET students.

To find which of the countless pedagogies works best for EET/TET programs, one must first understand how the current curriculum works. Each faculty member designs laboratory classes and a course project to illustrate the application of theories to a particular system or platform. Students spend a significant amount of time learning to use the system before applying the theories. Different courses use different systems, and as a result, students spend inordinate amounts of time learning these systems instead of learning the core knowledge the faculty members intended for the students to learn. Another area for potential improvement is in the use of the software. Depending on the personal preference of each faculty member, different software tools are used in different courses. Some courses do not use simulation as a tool to bridge the classroom lectures and laboratory tasks.

With the challenges and current process well understood, several methods were identified to be potentially effective: Modeling, simulation, and virtual laboratories; Curriculum integration; and Problem based learning.

### **Modeling, Simulation, And Virtual Laboratories**

Traditionally, classroom lectures and laboratory exercises are separate activities in student learning. The belief is that students will learn theories during classroom lectures and then conduct laboratory exercises to reinforce the theories learned. However, since the lectures and the experiments are conducted at different locations and different times (days or even weeks apart), some students treat them as completely unrelated activities. In the last decade, there has been an increased use of modeling, simulation, and virtual laboratories in engineering programs because they can bring “laboratories” to classrooms. The effectiveness of virtual laboratories in engineering undergraduate teaching and learning is well-documented [7,21,27,28,29]. Students see how a theory taught in a classroom can be applied to a virtual laboratory right after the introduction of the theory during the same class. The connection between theories and practical applications is made immediately instead of a few days later in the laboratory class. Simulation tools also allow students to familiarize themselves with test setups, test procedures, and expected test results before laboratory classes and to conduct quick checks for troubleshooting during laboratory classes. With the low-cost student version of software packages, students can prepare for their laboratory classes using university computing facilities, home computers, and laptops at times that are convenient for them. Through extensive use of simulation tools, students will be better prepared for the laboratory classes. Seamless integration of classroom and laboratory experiences through modeling, simulation and virtual laboratories will improve students’ analysis, design, and troubleshooting capabilities. In turn, this integration ensures effective use of limited laboratory resources.

### **Curriculum Integration**

Curriculum integration is a methodology widely used by educators to improve students’ educational experiences [2,4,9,11,17,19,23,26]. The vertical integration of curriculum is an effort to link the knowledge and skills taught in upstream courses to downstream courses. On the other hand, the horizontal integration of curriculum focuses on the repeated exposure to and use of certain knowledge, skills, or processes across courses in an educational program. Naumov *et al.* provided a straightforward diagram for vertical and horizontal curriculum integration, as illustrated in Fig. 1 [26], where lower numbered courses are upstream courses and higher numbered are downstream courses).

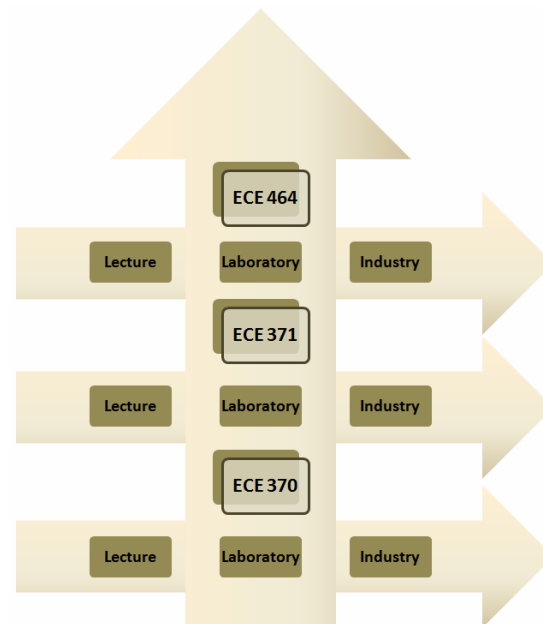


Figure 1: An example of vertical/horizontal curriculum integration [26]

Mahajan *et al.* [19] used curriculum integration by allowing students to use the same experimental set-ups in multiple courses and build upon the work done in previous laboratories of the same course, as well as those of previous courses. Layton *et al.* [17] generalized the definition of vertical integration to encompass mentoring and cooperative learning by using more experienced students to help and guide less experienced students. Farris *et al.* used a similar approach in final design projects that involved students in the same discipline but different class years, e.g., freshman and junior engineering students. The projects were also horizontally integrated by involving students from different disciplines. These different works in the literature show that curriculum integration is a very effective methodology for learning. This is especially true when used in course projects and software tools. Curriculum integration has been successfully used for object-oriented software design projects [5] and learning software tools such as MATLAB [33,35] and PSpice [23]. Some efforts have been made for a vertically integrated curriculum from freshman to senior [13,16]. Berkey *et al.* even proposed a model for vertical integration of innovative industrial projects in the mathematics curriculum at all levels, from middle and high school, through undergraduate programs and up to graduate programs and faculty research [2].

### Problem Based Learning (PBL)

PBL [1,14,34,37] is another learning and teaching strategy that works effectively for engineering technology students. Originating in medical education, PBL is now extensively used in engineering education. In PBL, relevant problems are introduced to students to provide the context for learning. Students, working cooperatively in teams to solve complex open-ended, real-world problems, are the center of learning, and the instructor becomes a facilitator. Usually, a PBL problem is multi-disciplinary in nature, involves the integration of concepts, encourages problem-solving strategies, and relies heavily on student initiative to locate resources and use the information they find. Seeing how a practical problem can be solved using knowledge they learned can motivate the students for deep learning and improve their higher-order thinking skills. PBL can also foster growth in teamwork and collaborative problem-solving skills. Many educators also have blended PBL with other pedagogies such as process-oriented guided inquiry learning (POGIL) and peer-led team learning (PLTL) to make it work for their specific courses [8]. For engineering technology students, it is beneficial to present problems that require hands-on experiential work. Course projects based on real-world problems are commonly used as PBL units, which work effectively for engineering technology students [3,10,14,36,39].

**Methodology**

The methodology adopted in this context is curriculum integration. Specifically, the curricular development effort consists of two critical components: vertical and horizontal integration of laboratory classes and course projects throughout the EET program.

In the vertical integration effort, laboratory classes and course projects in one semester are continued in a sequential course making each course an integrated part of a larger curriculum. It is very effective for sequential learning, especially when used in course projects [12,18,20,30]. The focus was on using a common platform and a common set of software tools in laboratory classes and course projects whenever possible. A common platform allows the students to spend less time preparing for the laboratories and course projects without compromising their ability to learn key knowledge or to gain hands-on experience. A downstream course would build additional features that are specific to the courses to the platform. Different aspects of common software tools will be learned in different courses.

In the horizontal integration effort, the basic functionalities of the common set of software tools are used repeatedly, thus reinforcing the software skills over several semesters, and a common process of modeling, simulation, virtual laboratories, and real experiments help improve learning efficiency.

With vertical and horizontal integrations of the curriculum, the students’ learning can be more efficient. One may argue that by using different systems for applications and different software tools, students become more versatile. Based on the authors’ own experiences, a balance needs to be achieved between learning efficiency and versatility. Most educators would agree that learning the core knowledge is more important than being versatile in the application of systems or software tools.

**IMPLEMENTATION**

Starting in the Fall 2008 semester, the curriculum integration effort was piloted with several courses within the EET program. A DC permanent magnetic motor was identified as a common platform that could be used in several courses including Digital Electronics (ENTC 219), Power Systems and Circuit Applications (ENTC 211), Instrumentation (ENTC 359), Microprocessors (ENTC 349), and Control Systems (ENTC 462). A breadboard implementation of a motor controller was first designed and then later converted to a PCB version. Two course projects were developed based on using the DC permanent magnetic motor as their application platform. MATLAB, Multisim/Ultiboard [25], and LabVIEW were selected as the common software tools to be used in courses, including Digital Electronics (ENTC 219), Power Systems and Circuit Applications (ENTC 211), Electronics (ENTC 350), Electromagnetics (ENTC 355), Electronic Instrumentation (ENTC 359), Control Systems (ENTC 462), and Capstone Design (ENTC 419/420). Finally, two virtual laboratories were created in MATLAB. These courses and their relationships are shown in the Fig. 2.

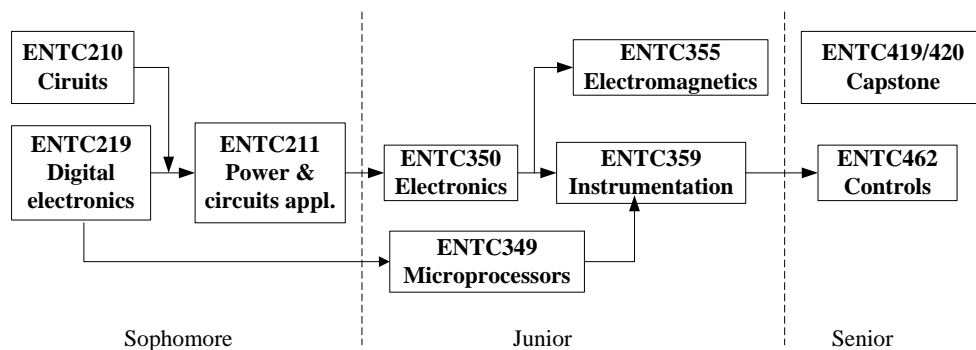
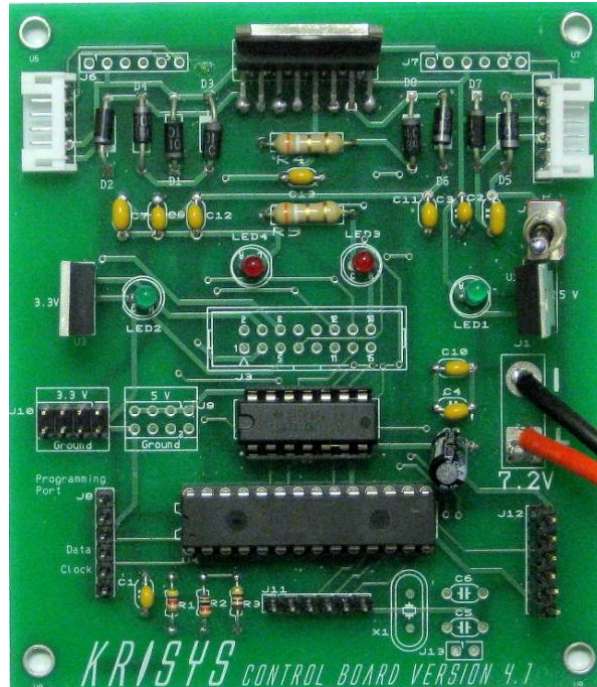


Figure 2: Curriculum flowchart for relevant courses

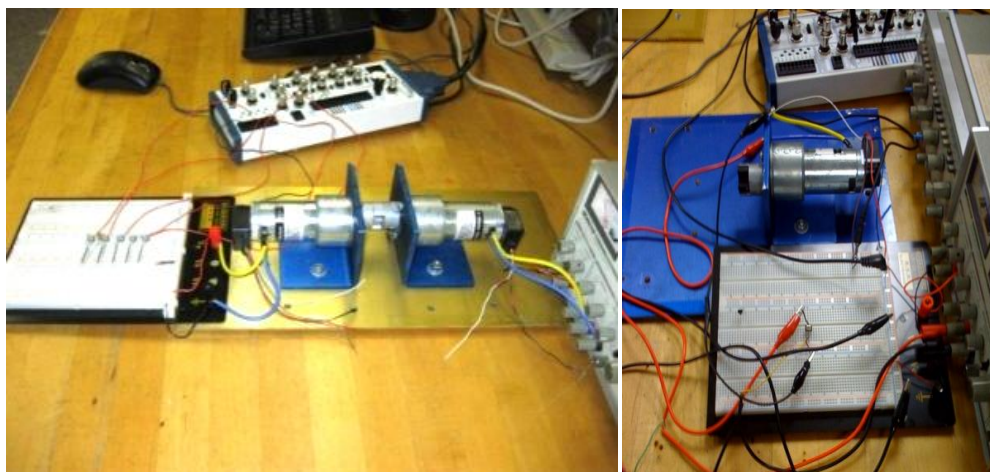
**DC Permanent Magnetic Motor**

DC permanent magnetic motors are widely used in industry for their low cost, ease of control, and reliable performance [31]. They are also used successfully by other engineering educators [32] for curriculum improvement purposes. The motor principles can be explained in a straightforward way. Digital controllers [6], with software or hardware implementation, can be implemented to control the speed. It requires instrumentation to measure the speed for closed loop control design. Based on these considerations, several low cost motors, including the IG220019\*00015R motor from Digilent, were tested as the common platform for vertical curriculum integration.



**Figure 3: Board layout and a finished PCB (ENTC 219)**

A printed circuit board (PCB), shown in Fig. 3, was designed and used in Digital Electronics (ENTC 219) to control a mobile unit in the course project.



**Figure 4: Setup of motor/generator (left) and load control and motor speed control (right)**

Breadboard versions of a motor/generator test stand and motor control test stand, as illustrated in Fig. 4, were used in Power Systems and Circuit Applications (ENTC 211). After the successful initial implementation, the breadboard motor test stands were redesigned using Multisim and Ultiboard, as illustrated in Figs. 5 and 6. The circuit was analyzed and simulated in the Power Systems and Circuit Applications (ENTC 211) class. Students populated the PCB and used it in their course project.

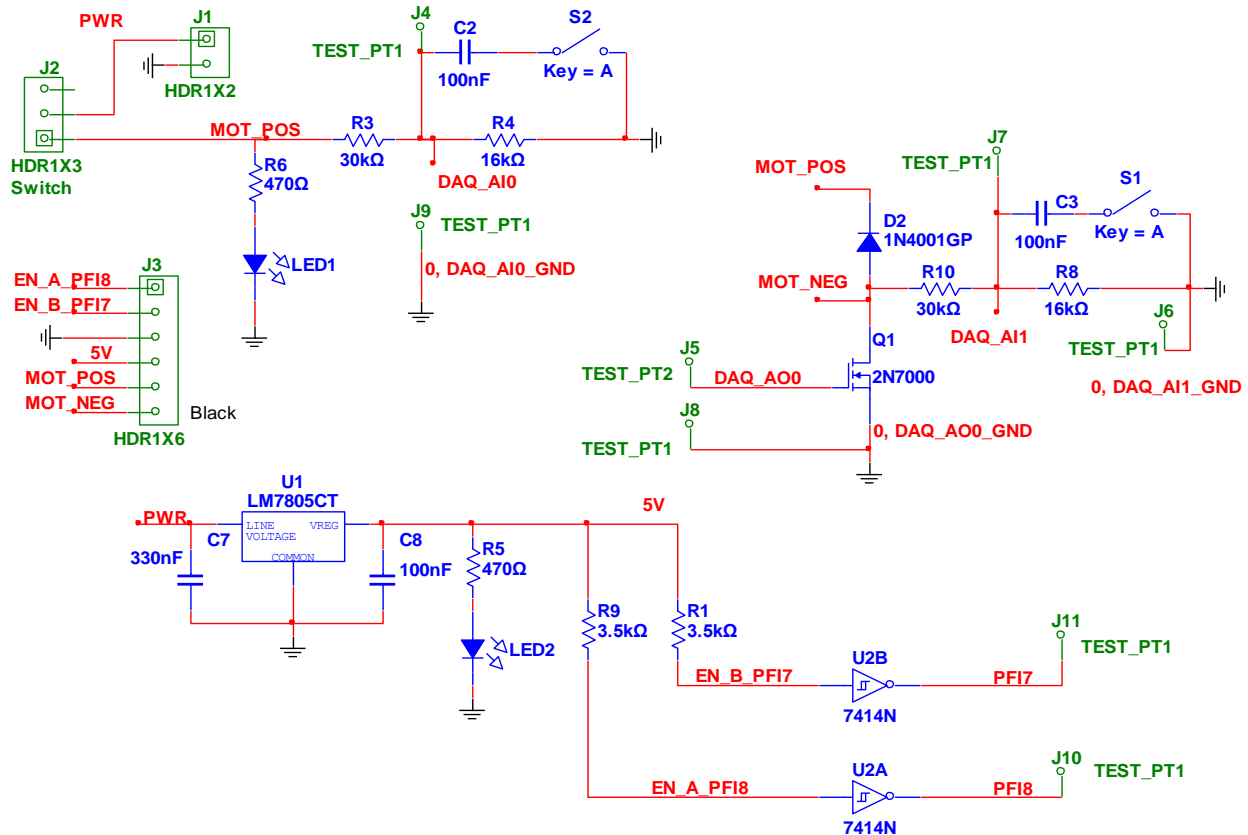


Figure 5: Multisim Schematics

Students were required to come up with a design of experiments to determine the motor parameters, such as resistance, inductance, torque gain, friction torque, and inertia, in the course project in ENTC 211. Students in ENTC 211 had already taken ENTC 219, both sophomore level courses, and thus had some experience with the principle and operation of the motor. Modeling and simulation were used to analyze the motor, and as a result, students had a deeper understanding of the motor principles and operation. What they learned in ENTC 219 was reinforced in ENTC 211. In a junior level course Electronic Instrumentation (ENTC 359), the same motor test stand was used in the laboratory classes and course projects, this time with an instrumentation focus. A LabVIEW based motor controller was given to students in ENTC 211. When they moved to ENTC 359, they were asked to add Modbus digital communication, temperature measurement, and closed loop control to the LabVIEW Virtual Instrumentation (VI) [24]. The authors intend to continue this curriculum integration by using the motor test stand in Control Systems (ENTC 462) where students would develop more sophisticated controllers to achieve better performance.

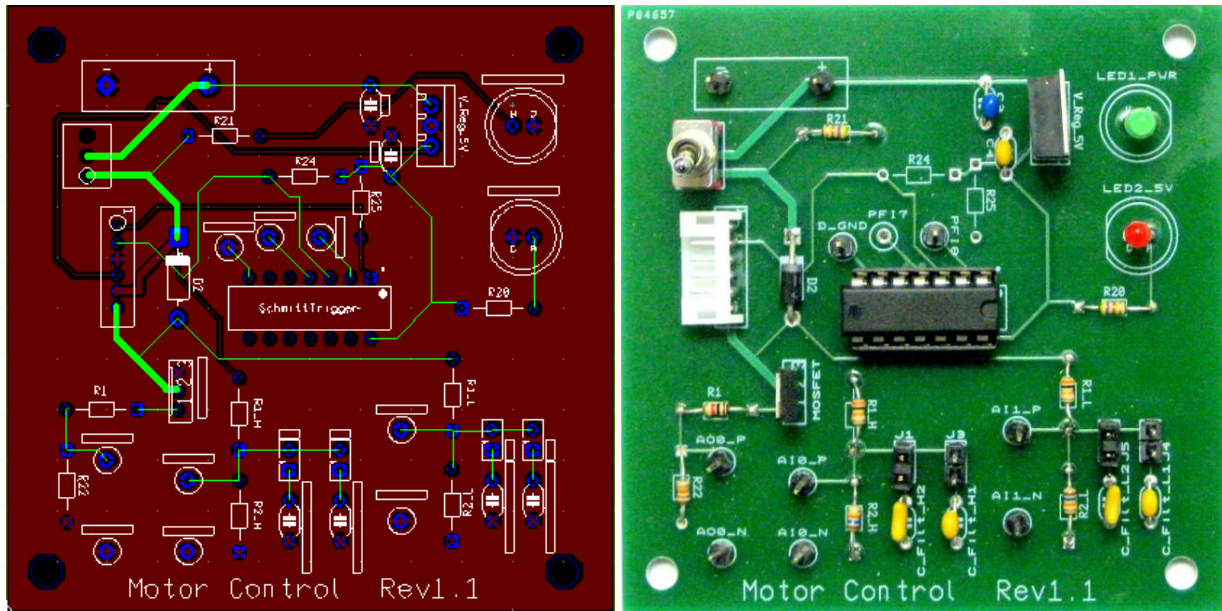


Figure 6: Board layout and PCB (ENTC 211)

### Modeling, Simulation And Virtual Laboratories

Early exposure to different software packages can effectively shift some of the learning from junior and senior level courses to lower level courses. This in turn will make the overall program curriculum more balanced. It will also allow for repetition in learning tools, methodologies, and processes, and makes students’ learning more effective [38].

MATLAB is a software tool widely used in academia and industry for dynamic system analysis, control algorithm design, and many other purposes. It is an appropriate tool for Power Systems and Circuit Applications and Control Systems. Multisim/Ultiboard are popular circuit analysis and design software tools. LabVIEW is widely used in industry for instrumentation during research and development. Table 1 shows the potential for curriculum integration in regards to software tools.

Table 1: Software Used Within EET Program

Year	Course	Multisim/ Ultiboard	MATLAB	LabVIEW
2	Circuits Analysis			
	Digital Electronics			
	Power Systems & Circuit Application			
3	Electronics			
	Electromagnetics			
	Electronic Instrumentation			
4	Controls			
	Capstone Design			

Multisim was introduced in Circuit Analysis and Digital Electronics as a basic circuit simulation tool. It was then used in Power System and Circuit Application for schematic capturing, simulation, and board layout. Students used the basic simulation feature with more components added in downstream courses such as Electronics, Electromagnetics, and Electronic Instrumentation. To emphasize the use of modeling, simulation, and virtual laboratories, a third order model for the motor was introduced to the students in ENTC 211:

$$\begin{aligned} \frac{di(t)}{dt} &= \frac{1}{L}e_a(t) - \frac{R}{L}i(t) - \frac{1}{L}e_b(t) \\ T_m(t) &= K_i i(t) \\ e_b(t) &= K_{emf} \frac{d\theta}{dt} \\ \frac{d^2\theta}{dt^2} &= \frac{1}{J}T_m(t) - \frac{1}{J}T_l - \frac{1}{J}T_f \end{aligned} \tag{1}$$

where  $K_i$  is the torque constant, in  $N\text{-m/A}$ ;  $K_{emf}$  is the back-emf constant, in  $V/(rad/sec)$ ;  $i(t)$  is the armature current, in  $A$ ;  $R$  is the armature resistance, in  $\Omega$ ;  $e_b(t)$  is the back emf, in  $V$ ;  $T_l(t)$  is the load torque, in  $N\text{-m}$ ;  $T_m(t)$  is the motor torque, in  $N\text{-m}$ ;  $T_f(t)$  is the friction torque, in  $N\text{-m}$ ;  $\theta$  is the rotor displacement, in  $rad$ ;  $L$  is the armature inductance, in  $H$ ;  $e_a(t)$  is the applied voltage, in  $V$ ;  $J$  is the rotor inertia, in  $kg\text{-m}^2$ ; and  $K_{emf} = K_i$ . A MATLAB model was derived based on equation (1):

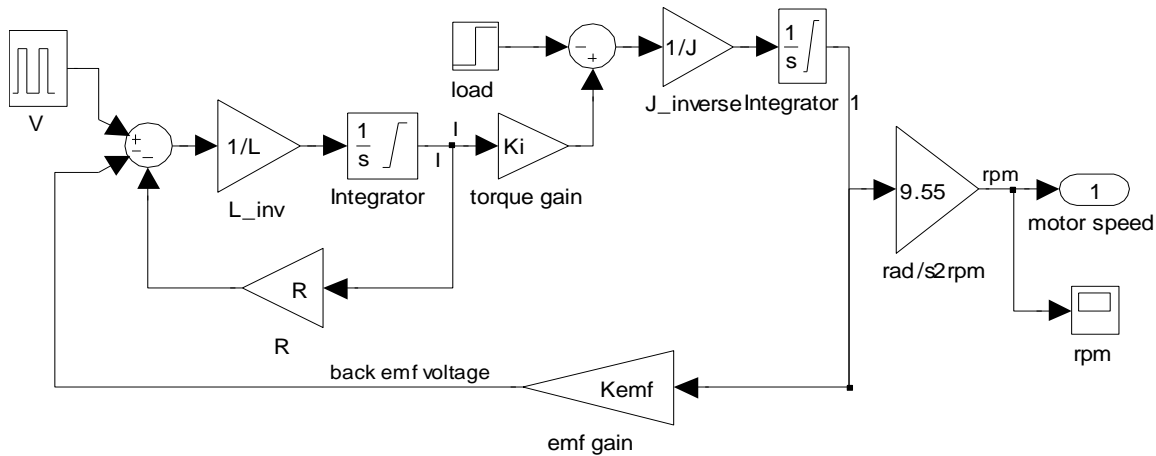


Figure 7: Simulink model for the DC motor

This model was used by the students to simulate the motor in the MATLAB environment. Virtual laboratories were designed for students to become familiar with motor characteristics and operations. Before the real test stand was built and tested, students ran simulations so they knew what to expect in the real tests. They also used simulation to troubleshoot the motor test in the laboratory.

**EVALUATION**

Two anonymous surveys were conducted at the end of the Spring semester in 2011: one for ENTC 211 students and the other for the ENTC 359 students. Students in ENTC 211 took ENTC 219 in the previous semester. Students in ENTC 359 had experienced the curriculum integration for four semesters in multiple courses. Each survey includes questions unrelated to the curriculum integration effort, only relevant questions are analyzed in this paper. Students were asked to assign a numerical value to each question – with 5 being strongly agree, 4 being agree, 3 being neutral, 2 being disagree, and 1 being strongly disagree. The sample size for the ENTC 211 survey is 14. The sample size for the ENTC 359 survey is 24. Students were told that the survey was for curriculum improvement, to be used in a research paper, and would have no impact on students’ grades. The relevant questions, the survey results are listed as follows.



ENTC 211 Survey

- Q3: My experience in ENTC 219 (soldering, motor operation) helped in the course project.
- Q4: Using motor control in ENTC 219, ENTC 211 saved me time in course project.
- Q6: Multisim is a useful tool for electronics engineering technology students.

Table 2: ENTC 211 Student’s Survey Raw Data (14 Samples)

Q3	5	5	5	5	5	2	4	4	5	4	2	5	4	4
Q4	4	5	5	5	5	4	4	4	5	4	3	5	4	3
Q6	2	4	3	3	5	2	4	4	5	4	4	5	5	5

ENTC 359 Survey

- Q1: Using motor in ENTC 219/211/359 laboratories and course projects saved me time in learning the platform without compromising the learning of critical knowledge.
- Q2: Learning and using Multisim/Ultiboard in ENTC 211 and other courses helped me in ENTC 359.
- Q3: Multisim/Ultiboard and LabVIEW are useful tools for electronics engineering technology students.
- Q4: Using simulation tools helped me in preparing for laboratory work.
- Q8: Learning software tools in one course and using them in other courses worked best for me.

Table 3: ENTC 359 Student’s Survey Raw Data (24 Samples)

Q1	3	4	3	3	4	3	4	4	4	5	5	5	4	3	3	5	5	5	4	4	5	4	5	5
Q2	5	4	4	4	4	4	2	3	2	3	5	2	2	4	5	3	4	3	3	4	4	5	5	5
Q3	5	4	3	3	5	3	5	4	3	4	5	4	4	3	2	5	4	5	4	4	3	5	5	5
Q4	3	4	4	4	5	4	5	5	4	4	5	3	5	4	5	5	3	5	3	3	4	4	3	4
Q8	5	4	5	4	4	2	1	5	5	5	5	5	5	5	5	3	3	4	5	4	5	1	3	

Statistical analysis of the survey data was conducted using Minitab [22]. Figure 8 illustrates the summary of the statistical analysis result for Q4 in the ENTC 359 survey. The mean value is 4.0833; the standard deviation is 0.7755; The 95% confidence interval for mean value is (3.7559, 4.4108); The 95% confidence interval for standard deviation is (0.6028, 1.0879).

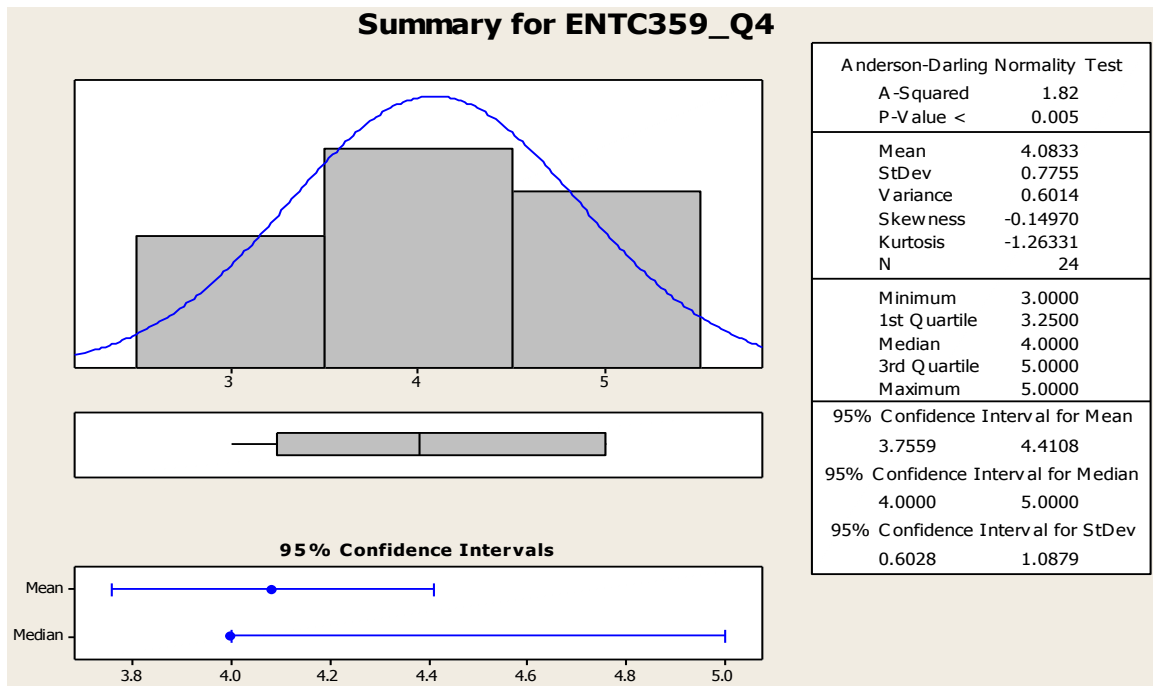


Figure 8. Statistical analysis of survey data

Graphs similar to Fig. 8 can be plotted for all the questions in the surveys. The results are summarized in Table 4.

**Table 4: Statistical Analysis Results Of The Survey Data**

	Mean	Stdev	95% confidence interval for mean	95% confidence interval for Stdev
ENTC211_Q3	4.21	1.05	3.61-4.82	0.76-1.69
ENTC211_Q4	4.29	0.73	3.87-4.71	0.53-1.17
ENTC211_Q6	3.93	1.07	3.31-4.55	0.78-1.73
ENTC359_Q1	4.13	0.8	3.79-4.46	0.62-1.12
ENTC359_Q2	3.71	1.04	3.27-4.15	0.81-1.46
ENTC359_Q3	4.04	0.91	3.66-4.43	0.71-1.27
ENTC359_Q4	4.08	0.78	3.76-4.41	0.60-1.09
ENTC359_Q8	4.00	1.31	3.42-4.58	1.01-1.87
Average	4.05	0.96		

The means for all eight questions were around 4.05 (agree). The standard deviation is around 0.96. Even though the sample size of 14 is small, the statistical analysis result still shows that with 95% confidence the mean values are high and the standard deviations are reasonable. This leads to a conclusion that the overall students' responses were very positive. Some sample comments are listed as follows:

*"I had no experience in soldering and motor PWM control before I took 219. I found these experiences helpful in 211 and I am looking forward to uses these again in other courses."*

*"Using similar tools and motors helped a lot."*

*"I learned how to use a motor in a robot in ENTC 219. Now I am learning how a motor works in ENTC 211. It is a good flow. I feel like I am becoming an expert in motor."*

*"We learned Multisim in ENTC 211, 250, 355, and 359. Through these courses I realized the importance of Multisim/Ultiboard."*

*"Now we have learned so much about Multisim, Ultiboard, and LabVIEW, I feel that I have a better chance to find jobs next semester."*

*"The tool overall proves to be very helpful and cost effective before actually creating a real prototype."*

*"Before testing out the motor we can always test the motor with the simulation so we know what results to expect. The simulated motor can give us a good idea what we need to change or what we need to replace with the current motor."*

*"I believe that this motor lab has incredible potential in providing the students with a look at many aspects of a design process that a motor might be involved in. After completing this lab, I now have a complete understanding of the motor and have an appreciation for the mathematics that can be used to foresee the performance."*

*"I learned a little of all these software packages, but am not an expert in any one of these. We need more in-depth learning of these tools."*

Evidently there are drawbacks to the course project vertical integration. One student made the following comment:

*"Using motor as the common platform for all course projects did save me some time. But I lost opportunities in learning other interesting applications."*

Another student commented: *“It has helped, but since we don’t try using other things, we get too comfortable.”*

Before the experimentation of vertical integration with the common platform, the top students in each class were able to handle multiple course projects. For those students, using a common platform is a step back in their educational experience. The student response to Q1 in the ENTC 359 Survey has a mean of 4.21 with a 95% confidence interval of (3.79-4.46). This shows the vast majority of the students learned the core knowledge more efficiently with the vertically integrated curriculum. To address the needs of the top performers in each class, an option of using a different system will be offered to the students. This will further improve the balance between learning the core knowledge and being more versatile.

Since the curriculum integration effort is an on-going research project, more surveys will be conducted. The feedback from students will be used to further fine tune the curriculum improvement effort.

## **CONCLUSION AND DISCUSSION**

Inspired by a problem of students not having enough time to work on many laboratories and course projects, a research question of how to improve the students’ learning efficiency was studied in this article. A combination of the use of modeling, simulation, virtual laboratories, curriculum integration, and problem based learning was adopted as the methodology for solving the research question.

A common set of software tools are introduced, starting at the sophomore level, to students in the EET curriculum; these are then used in several junior and senior level courses. Through early and repeated exposure to these tools, students learn to use them more effectively in solving various engineering problems in laboratory and course projects. Modeling and simulation are also emphasized as a bridge between theories learned in classroom and laboratory work. As a result, students are better prepared when they come to laboratory class. The time they spend on trial-and-error is greatly reduced. A DC permanent magnetic motor was selected as one of the common hardware platforms used in laboratory classes and course projects for multiple courses. By integrating the laboratory classes and course projects through the EET curriculum, students are allowed to focus on the knowledge they are required to learn. They can spend less time learning different software packages and building application platforms for course projects.

Preliminary results showed that the student work load is reduced without compromising their learning, and the curriculum integration method is effective in improving student learning. The initial success will lead to program-wide implementation of curriculum integration. Not only is the common platform of DC permanent magnetic motor used in several course projects, but some of the projects also build on top of others. For example, instrumentation will be built for the motor in the Instrumentation course project; Control algorithm will then be developed in the Controls course project based on what the students developed in the Instrumentation course; the motor with instrumentation and control may be used in a senior design project as the actuation part of the overall system. This way, a students’ educational experience becomes seamlessly integrated into a continuous flow. Additional platforms may also be identified for other courses where a DC motor is not an appropriate application platform.

As an effort to continually improve the EET program, more data will be collected for evaluation of the effectiveness of the curriculum integration effort. Future results will be quantitatively and qualitatively evaluated through student and faculty surveys and feedback from former students and industry. Results from this research effort will continue to be made available to the educational research field through publications and presentations.

Since the goal of this paper is to improve learning efficiency, the results in this paper are generally applicable, with appropriate modification, to a broad range of higher education programs. The laboratory classes and course projects were chosen because of their importance for ET students.

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