

# Active Learning Approach for Enhanced Student Learning in Electromagnetic Compatibility Course

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This paper presents an active-learning approach for enhanced learning in a course on Electromagnetic Compatibility offered as an elective to undergraduate and graduate students in electrical and computer engineering majors. Discovery based laboratory demonstrations, simulations and construction projects were created in the course to enable student centered original educational experience. Suitable assessments were conducted to test the learning outcomes. Anonymous student survey was also conducted to test student perception of understanding of course materials. Results show that active-learning leads to improved student outcomes.

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## Introduction

Over the years, electronic systems have evolved to operate at frequencies above one Giga Hertz. In order to understand the operation of such systems, knowledge of electronic circuits, signals and systems needs to be supplemented with a good understanding of essentials including relevant tools from applied electromagnetics. A course on electromagnetic theory that is offered to students of Electrical engineering majors provides knowledge of static electric and magnetic fields, time varying electromagnetic fields, high frequency effects in transmission lines, electromagnetic wave propagation and an introduction to antennas. Students do not get adequate information on Electromagnetic Compatibility (EMC) standards from the course on electromagnetic theory as this course is usually based on solving problems related to Maxwell's equations and understanding the transmission of electromagnetic energy.

Knowledge of standards in EMC is very valuable to a graduating student as most electronic products in the market now operate at clock frequencies that make it necessary for them to pass this standard before they are market ready. Further, a topic on overcoming challenges of transmission line effects is often not discussed in detail in a course on electromagnetic theory. Offering solutions to mitigate transmission line effects and providing signal integrity at high frequency through a course on EMC to students of computer engineering majors is highly relevant to the current manpower needs of the industry. A course on EMC offered as an elective to both Electrical and Computer engineering students therefore provides the much needed knowledge and information for students aspiring to engage in digital design and application of high frequency effects in

electronics [1-4]. Additionally it can be offered as an elective to graduate students in electrical and computer engineering. The textbook necessary to offer this course has been provided by Clayton R. Paul [5] and covers in a comprehensive manner the topics relevant to the course. It includes appendices which fill any gaps in learning by students on prerequisites.

This paper examines active learning approach to teaching and learning of EMC and its impact on student learning outcomes. In the past, university departments lacked the basic laboratory test equipment needed such as spectrum analyzer, calibrated antennas and test facilities and it was suggested to partner with local industry to overcome this [1]. However, with USB based spectrum analyzer becoming available at affordable prices, most universities now have them for student use. The mixed domain oscilloscopes also offer FFT based spectrum analysis, are inexpensive and come with a VGA port for projection. Hence it is now easy to perform in-class demonstrations.

With the most basic equipment such as spectrum analyzer, oscilloscope, LCR meter and simulation software such as PSPICE or Multisim, several discovery based experiments can be included as active learning tools. This paper presents the findings of a study of using them and their impact on student learning outcomes.

## Teaching Methodology

This section describes the student outcomes, topics covered during the course and teaching methods used to achieve the outcomes. The students taking EMC course will be able to i) explain radio-frequency emissions from electronic devices and the need for electromagnetic compatibility, ii) understand

Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) regulations in the U.S., Canada and the European Union, iii) solve problems related to signal integrity, iv) examine and identify ways to prevent common EMI problems in power supplies, cables and digital systems, v) examine ways to minimize interference and achieve electromagnetically compatible systems, and vi) use PCB design techniques for EMC compliance.

In order to achieve these student outcomes, the EMC course includes the following topics -i) Introduction to EMI and EMC ii) EMC regulations for conducted and radiated emissions iii) Signal Spectra iv) Basic electromagnetic theory v) Transmission lines and signal integrity vi) Non-ideal behavior of components including their performance to mitigate EMI vii) Components used for compatibility such as common mode chokes and Ferrite beads viii) Conducted emission and its measurement including methods to mitigate conducted emissions ix) Power line filters x) Radiated Emission and its measurement including methods to mitigate radiated emissions xii) System design for EMC. The text book used for the course is ‘Introduction to Electromagnetic Compatibility’ [5].

The topics were covered through lectures, student reading assignments, class review problems, discovery based laboratory demonstrations, simulations and construction of diagnostic tools, hands on construction projects to practice the concept of achieving EMC. The students taking the course were all graduate students. However, it could be offered to undergraduates as well. Many of the simulation exercises used have been presented in [3] and [5]. The demonstrations for this course were either selected from those available in various literatures [6-8] or were adapted based on availability of equipment. While some topics were purely based on lectures and problem solving, others included a demonstration and/or simulation. The method used is presented in the Table 1.

An introduction on the details of the use of spectrum analyzer was presented using MDO 3000 Tektronix scope. The students were instructed on construction of basic diagnostic tools for studying the electromagnetic emissions such as current probe and loop sensor. They were also instructed on the development of electromagnetic interference mitigation tools such as common mode choke and green wire choke for application in power line filters. Students were supplied with materials to construct them and use them in their project.

	Topics	Lecture/Activity
i.	Introduction to EMI and EMC	Lecture and Class Review Problems
ii.	EMC regulations for conducted and radiated emissions	Lecture and Class Review Problems
iii.	Signal Spectra	Simulation, Demonstration, and Lecture
iv.	Basic electromagnetic theory and Antennas for EMC	Lecture and Reading assignment, Class review Problems
v.	Transmission lines and signal integrity	Simulation, Demonstration, Discovery-based experiments and Lecture
vi.	Non-ideal behavior of components including their performance to mitigate EMI	Simulation and Discovery-based experiments and Discussions
vii.	Components used for compatibility such as common mode chokes and Ferrite beads	Simulation and Demonstration and Lectures
viii.	Conducted emission and its measurement including methods to mitigate conducted emissions	Simulation, Discovery-based experiment, Lecture
ix.	Power line filters	Simulation and Lecture
x.	Radiated Emission and its measurement including methods to mitigate radiated emissions	Demonstration and Lecture
xi.	System design for EMC	Lecture, Class Project and Project presentation

Table 1: Class Topics and Mode of content Delivery

An LCR meter is commonly used tool in the laboratory for students to measure the value of inductance or capacitance. However, the parasitic element values are generally ignored during such measurements. In this course, students are advised to make a note of the parasitic values and simulate the impedance characteristics of inductors and capacitors. This measurement was later used in simulating the non-ideal

behavior of components used in mitigation of electromagnetic interference and the consequences.

The discovery-based laboratory demonstrations included 1) studying the spectrum of trapezoidal clock signals, 2) understanding the non-ideal behavior of inductors and capacitors, 3) measuring common mode currents with current probes from a microcontroller board driving a DC motor, 4) measuring radiated emission from a PCB operating at few hundred Mega Hertz with a loop sensor, and 5) studying the effect of transmission lines matches on digital waveforms and matching techniques to mitigate this problem. Students were allowed time to set up and use the equipment to understand the concept.

A list of simulation exercises that were performed during the course were: 1) Fourier representations of digital signals with rise time and fall time, 2) use of RC networks to suppress high frequency components of digital pulses and its impact on the response of the digital waveform, 3) impedance characteristics of Line Impedance Stabilization networks (LISN) used in conducted emission measurements, 4) determination of self-resonance frequency of the non-ideal capacitors and non-ideal inductors, 5) study of transmission line effects and signal integrity, 6) study of impedance matching techniques, and 7) determination of insertion loss of power line filters.

In order to integrate the knowledge gained from various topics and the activities throughout the course students were assigned a class project. It was the design and implementation of DC-DC buck convertor on a general purpose printed circuit for minimal emissions.

It may be noted that along with providing hands-on experience, several problems were solved during class as topics were reviewed. Since a passing or failing of standards in EMC depend on measured values, knowledge of problem solving skills becomes very important to the understanding of the course material. Homework was assigned to reinforce the problem solving skill. The text book provided several exercise problems at the end of the chapter for this purpose.

### Analysis

An anonymous web-based survey was conducted to determine whether the students agreed that the active learning modes of instruction contributed to the enhanced students' learning. Some of the survey questions used to test this was: whether the class review problems, the homework problems, the power-point presentations and material posted on Blackboard (Bb) help in learning the course materials. Other questions

included if he in class demonstration, the simulation, use of spectrum analyzer and other equipment in class as well as tests helped with learning the course material. The survey also included questions on whether the class project helped with learning, whether the course helped integrate, improve and hence apply the student's knowledge of circuits, systems and electromagnetics, and if the course is likely to be useful in the career of the student in future".

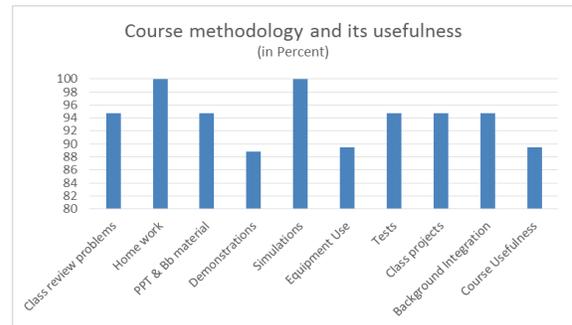


Figure 1: Course Methodology and its Usefulness

The results as shown in Figure 1 indicate that students benefitted greatly from simulations and homework problems. It is important to note that more than 85% of students agree that all the methods used for delivery contributed to their learning. Several problems in the course require skills acquired from a sequences of courses on circuits, signals and electromagnetism. The survey confirmed this, as 95% agreed that the course integrated their knowledge of circuits, systems and electromagnetism. Of the nineteen students who responded, 89% perceived the course is likely to be useful for them in their careers.

The anonymous web-based survey included questions that get students' own assessments of the areas where they i) have gained knowledge, ii) were able to improve their skills iii) were able to apply knowledge. The survey revealed that in most areas most students perceive themselves as having met the knowledge, application or skill gain expected in the course objectives. The skills gained through demonstration, simulation exercises and construction projects as perceived by students from survey are shown in Figure 2. Survey question were addressed to find if they possessed the skill to construct the EMI mitigation products or construct diagnostic tools and perform measurements with a spectrum analyzer using them. Of the nineteen respondents 89% agreed that they have gained skills required for the EMC analysis.

The survey further probed the students own perception of their ability to apply the knowledge for problem solving that they have gained during the

course. Questions on the survey directly related the topics discussed and problems solved during class and in the homework. For example, they included questions if students could, “test if a product passed or failed an EMC standard, estimate spectrum of digital signals and use capacitors to suppress harmonics, determine the value of EMI mitigation products such as green wire choke and common mode chokes, design a power line

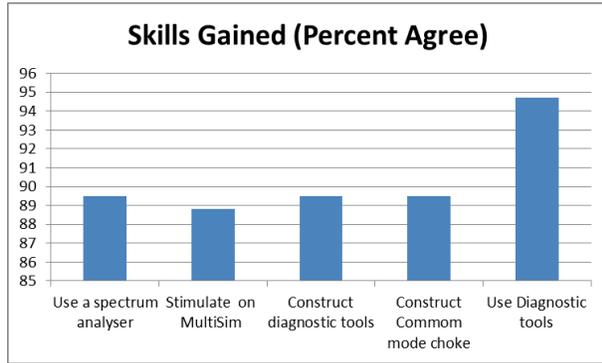


Figure 2: Skills gained through demonstration and measurements during the course

filter for achieving a specified insertion loss, perform impedance matching for signal integrity, choose suitable grounding techniques to minimize EMI, and use appropriate PCB techniques for EMC”. The survey response indicated that 89% of students agreed that they had the ability to apply the knowledge of EMC as shown in Figure 3.

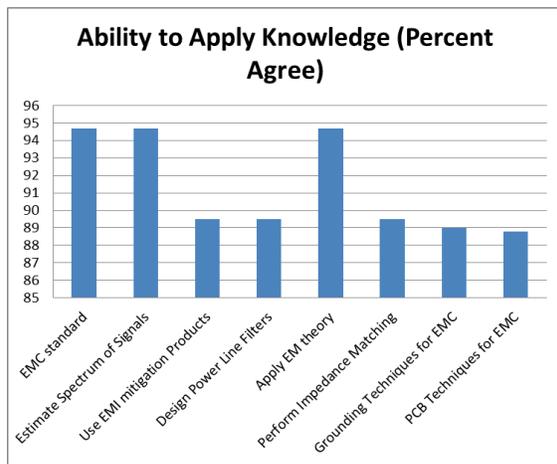


Figure 3: Perceptions on ability to apply knowledge

The student outcomes were measured through regular quizzes, tests, problem-solving exercises, projects and examinations. Students receiving greater than 80% score on the test problems were considered as having satisfactorily met the outcome. Question relevant to

each of the outcome listed in the “Teaching Methodology” section was used for the assessment. Two questions on tests or quizzes were used for assessing each outcome except for the outcome “vi on use of PCB techniques for EMC”. The assigned project on DC-DC buck converter was used for assessing this outcome. It was found as shown in Figure 4 that for various learning outcomes, the percentage of students meeting the set standard was 70% or above for all outcomes except in the case of outcome iii. In a question relevant to outcome iii, a problem on impedance matching to improve signal integrity was assigned and only 62% of students reached satisfactory or above levels. Despite using both simulation and demonstration on this topic students had difficulty. This problem required the use of several concepts learned in order to arrive at the best impedance matching solution. More practice problems in this topic was thus essential for students to gain adequate confidence. The student survey on course methodology stressed the importance of class reviewed problems and homework problems.

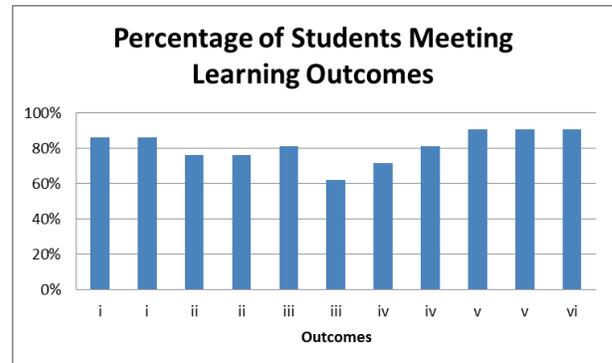


Figure 4: Percent Student meeting learning Outcomes

### Conclusions

The paper has reported the impact of active learning approach in a course on EMC. The present study clearly indicates that an active learning approach with multiple practical exercises have achieved the level of proficiency and skill in the area of EMC for students majoring in Electrical and Computer engineering. Hands-on construction projects provided opportunity for students to make measurements and test their design for EMC. Availability of low cost equipment in recent times has made this testing possible and enabled active learning approach.

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