



Student learning in a required Electrical Engineering (EE) course for non-EE majors: Perception of values for future work in multidisciplinary teams

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Abstract

Due to the unprecedented progress of analog/digital electronics and programmable devices, all engineering fields are getting intertwined with Electrical Engineering (EE) and non-EE engineering majors are required to take at least one EE course. But still, some undergraduate non-EE majors do not see the relevance of EE to their studies until they face real-world problems at workplace, when the opportunity for learning in required courses is already missed.

We strive to overcome this unfortunate tendency by combining research in engineering education and practical teaching of a large EE service course for non-EE majors from the College of Engineering, in two inter-related ways:

- i. Monitor and influence the students' perception of the value of learning EE; foster their understanding of the connectedness between EE and all fields of engineering, to help them achieve more in their major fields, and
- ii. Gradually evolve the course to make it more valuable for students, relevant to what they learn in their fields of major, to their future projects and work.

During each semester, we design surveys and regularly offer them to the currently enrolled students; analyze the statistics of their answers and get deeper understanding from reading their open-ended responses; and immediately apply our findings to teaching.

Here we report our work in Fall 2012, when the course structure was changed to enhance the lab experience, and present the results that reveal:

- The initial attitudes of students to this course
- The gradual evolution of their attitudes and what caused this evolution, and
- The growth of students' understanding of the connectedness between EE and all fields of engineering, and appreciation of the value of EE for their profession.

Some of our findings may serve as recipe for success for other service courses.

Background

We investigate the student learning in a large introductory, service course in Electrical Engineering (EE) for non-EE students, mostly from our College of Engineering. This report presents further development of our earlier studies reported at ASEE 2011 and FIE 2011 conferences [*Comment for Reviewers: Exact references are not given in order not to disclose our affiliation, etc.; they will be included in the final version of the paper*]. Here we broaden the scope of our study and deepen the analysis of the students' feedback.

The data presented here were collected in Fall 2012 when the course structure was changed to incorporate more Lab experiments: during the semester, every student is required to do 8 Labs (instead of 6 in previous semesters). Each Lab is completed within 2 hours of the scheduled time; students work in the lab in teams of two but submit their lab reports individually. Some of the new Lab experiments were especially designed for non-EE majors: for example, in Lab 2 they build a light-activated control circuit with a photocell as a light sensor and a MOSFET as electronic switch, which automatically turns On/Off the actuator (lamp or motor).

Before offering the new course structure in the Fall, many innovations were tested in the Spring 2012 (34 students enrolled). In the Fall 2012 semester, 156 students were enrolled, including 90 juniors and 64 seniors, with the most represented majors listed in Table 1.

Table 1. The demographics of students enrolled in Fall 2012

Engineering Major	Enrolled	Percentage
Mechanical	61	39.1
Aerospace	43	27.6
Nuclear and Radiological	22	14.1
Industrial and Operations	6	3.8

The main challenge of teaching a *required* EE course for non-EE majors is the *lack of interest of students to take it*: in their official University-wide evaluation at the end of Fall 2012, the average score of students' answer to the question "I had a strong desire to take this course" was 2.90 on the scale from 1 = Strongly disagree to 5 = Strongly Agree, while the average score on "I learned a great deal from this course" was 3.98.

Noteworthy, the policies of various Departments at the College of Engineering, which relate this course to the courses in the students' major fields are diverse: some Departments list this course as a pre-requisite to their courses (such as Aerospace lab course and a control course in Mechanical Engineering) and require C as a passing grade, while others count it merely as a graduation requirement and accept D+ to pass. This diversity of policies probably influences the diversity of students' attitudes, but in our surveys we do not link the students' responses to their fields of major.

Here we present the current state of our ongoing work focused on making this course more valuable for students, in two inter-related ways:

- iii. Gradually evolve the course to render it more relevant to the students' learning and projects in their fields of major, and
- iv. Influence the students' perception of the value of learning EE, which empowers them to achieve more in their major fields.

Detailed description of several innovative Lab projects and a brief overview of the entire sequence of Lab experiments is presented in a separate paper at 2013 ASEE Conference.

Purpose

Our ulterior goal is to create a better atmosphere for learning and teaching, by fostering the students' understanding of the interdependence of engineering fields and appreciation of the value of multidisciplinary learning for their professional growth.

Our practical goals intertwine Engineering education research with practical teaching of the course for non-EE majors. They include:

1. Monitor the non-EE students' perception of the EE course, its content, value, logistics, and work load. Promptly respond to the student feedback: make adjustments as needed during the same semester and/or for future semesters.
2. Encourage the students to relate their learning of EE to their major field of studies, future projects and work. Provide assignments that clearly connect EE to non-EE fields; emphasize applicability of EE to a wide variety of projects.
3. Reveal which parts of their learning of EE the students find most interesting, important and valuable for success in their field of major and professional growth. Use the information gained from student feedback to further improve the course.

Methods

Our research of student learning blends quantitative and qualitative methods¹⁻³. Our main focus is on the students currently enrolled in the course. For them we design surveys using a professional version of SurveyMonkey®, which allows us to:

- a) Obtain statistics on multiple-choice questions,
- b) Collect open-ended, essay-type answers, and
- c) Use two separate web sites – one for submission of students' answers and the other for submission of students' names. This feature is extremely important, because it ensures anonymity of student responses and – at the same time – allows the instructor to reward each participant with extra credit (see below).

Among the limitations of this method is that, in order to maintain anonymity, we could not connect the students' answers to their majors or assemble a “portfolio of responses” for an individual student to follow the evolution of their views during the semester.

During each semester, we offer the students enrolled in the course many surveys for various purposes, such as:

- d) Appreciate their perception and expectations of the course, including the particulars such as the balance of efforts between homework and the labs,
- e) Monitor the change of student perception of the value of learning EE and their interest in taking more EE courses,
- f) Assess the amount of time for completion of weekly homework and lab-related assignments, in order to make prompt adjustments if needed,
- g) Collect student opinions on the quality of learning resources such as discussion sections and materials posted online,
- h) Identify the more difficult topics on the forthcoming exam, in order to focus the exam reviews,

- i) Find out which aspects of the lab experiments the students found most interesting and relevant to future work, and what remained unclear, etc.

The use of surveys allows us to “break the glass wall” separating the instructor from a large, diverse student audience in the service course. Sincere and detailed answers to open-ended questions are similar in depth and value to what can be collected (at a much higher cost) in focus groups. The frequency of surveys and prompt availability of their results render this feedback formative: some of the necessary changes can be readily implemented during the semester.

An additional value of the student feedback involves continuity of the learners’ experience: at the end of every semester we ask students enrolled in the course to provide advice to the students who plan to take this course in the future, and we convey their (wisest) advice to new students as part of the course syllabus.

In order to provide incentives to students and collect feedback representative of the entire class, we award every participant of each survey with 0.1% extra credit on the 100% scale for the course. The maximal number of points that a student can earn via participation in surveys was 1.6% in the Fall 2012; for comparison, the reward for early submission of homework was ~3-fold higher. We believe that extra credit for participation is justified, because thoughtful feedback requires reflection on learning and teaching, which in turn stimulates meta-communication and comprehension of the course material. The average amount of extra credit for participation in surveys earned by students in the Fall 2012 was 0.86%, while the width of each letter grade bin was 4% (straight scale, no “curve”); thus extra credit points only slightly influenced the letter grade distribution. The average participation of students in the surveys was 62.6% in the Fall 2012 (156 enrolled).

Also, to encourage the students to think about their learning of EE and the relationships between engineering fields, we require that at the end of each Lab report they write a brief conclusion on what they learned in this Experiment, how they can apply this learning to their further studies and work, and what still remained unclear.

Another focus of our research is on the students who took the course in the past and either continued their studies at the University or graduated and started to work in industry. This audience is harder to reach, thus the results are limited, albeit very interesting. In this case, we use interviews (face to face or over the phone). The insights gained from conversations with former students make good, motivating stories in lectures and help us focus the teaching on those aspects of the course, which turned out to be most applicable to work and studies.

In this report we focus on those data collected in several surveys during Fall 2012, which are most relevant to the understanding of students’ attitudes to the course material, their *evolving* perception of its value for their fields of major, and the connections between this course and other courses offered at other Departments. The students’ answers to open-ended questions are not edited, except for correction of obvious typos.

Results and Discussion

In this section, which includes several subsections, we tell about our key findings made in Fall 2012:

- Describe some of the survey questions given to students
- Present the statistics of collected responses in a condensed form, and
- Quote interesting and representative answers to open-ended questions.

Also, we briefly discuss the meaning of collected results and outline what we think may be the recipes for success in future teaching of this and other service courses.

- ***Why the students take this course and what they expect of it***

In the “welcome” survey, which was completed *before* the first day of classes, we asked the students why they decided to take this course and what they expected of it. The results reveal a mixed picture, shown in Table 2, where the right column lists the percentage of participants who *agreed* (A) or *strongly agreed* (SA) with the suggested statement.

Table 2. Condensed summary of students’ answers to the “welcome” survey
~120 respondents

Question	Suggested Statement	SA+A
Why have you decided to take this course?	I always wanted to learn about electronics	70.3%
	It was not my decision: this course is listed as a graduation requirement	73.7%
	This course is required as a pre-requisite for my major courses	82.9%
What goals do you have for this course?	Learn about electronics to become a more intelligent user of it in everyday life	94.1%
	Understand Electrical Engineering for successful work in multidisciplinary teams	82.3%
	Learn hands-on skills that might be useful for my major courses	95.0%
	Apply electronics to projects in my major field	88.2%
	Learn the introductory material in this course and then take more EE courses	15.9%
Although I am not really interested, I want a good grade to maintain my GPA	50.8%	

Evidently, the percentages of answers to each question do not add up, which indicates that students have mixed motivations and goals. This assumption is confirmed by their comments, like the following (quoted without editing).

On their decisions to take this course:

“Although this course is a requirement for my major, I can still appreciate the need it has in my future career and I am excited to expand my knowledge on the subject.”

“I am really only taking this course because it is required to graduate with a degree in Aerospace Engineering. I haven't had lots of experience in the subject matter, but I am more than willing to learn and seek help if needed.”

“I do have a little interest towards electronics, however I wouldn't have opted it for it if it weren't a requirement for my major as I am already over burdened with several courses.”

On their goals for this course:

“I want to learn this material because it will make me a better person to be able to understand electronics and I am interested in learning about circuits. Also I want to do well to raise my GPA not just maintain it.”

“Just want a good grade. Don't really need this in the field I'm going into, but hopefully I'll be able to improve my analytical thinking and problem solving skills.”

“Obviously my goal is to get a good grade in the school. I also still think that it is important to actually learn the material to use in work or everyday life. I worked at a company this summer that makes interconnects which deals heavy with electronics so it would be interesting to see how this class compliments stuff I already know and as well as what I can further my knowledge.”

The students' expectations for the course were also mixed but mostly optimistic:

“I expect to understand electrical engineering from new points and cover fields I have not had any previous experience with.”

“I expect this course will be difficult. I feel there will parts of this course that I will like, but I will not enjoy the majority of this class. As long as I do well, I will have happy memories of this class.”

“My expectations are that I will be competent in analyzing and building circuits. Hopefully these skills will be especially useful as I take higher level engineering courses.”

The following list of thoughtful expectations might serve as a reminder for the instructor:

“To have the material presented in a clear and non-assuming manner. I feel like I, and a lot of other people that will be in the class, will have very little background with this kind of material. That being the case, it would be my hope that things

were explained as clearly and simply as possible, as to not confuse people from the get-go. Also, I would expect the class to understand that we are taking other classes, some of them a lot more difficult than this one, and that excessive amounts of work would actually be counter-productive to our learning.”

Noteworthy, the students’ responses reveal a mixture of internal and external motivations⁴ for taking the course and for learning a new field of engineering.

- *How the students’ interest in the course material evolves during the semester*

After 2 weeks of studies, we offered another survey, with the first question “How interested are you about the course?” The results are shown in Table 3. The numbers in bold font indicate the most frequent answers in this and the following tables.

Table 3. The growth of student interest in the course material after two weeks
The numbers of respondents are in parentheses (total, 101)

	Extremely interested	Moderately interested	Neither interested nor disinterested	Moderately disinterested	Strongly disinterested
Before taking the course, how interested were you in learning the class material?	5.9% (6)	48.5% (49)	27.7% (28)	14.9% (15)	3.0% (3)
After two weeks of classes, how interested are you in learning the course material?	11.9% (12)	54.5% (55)	26.7% (27)	4.0% (4)	3.0% (3)

Table 3 shows that the students’ interest in the course material has grown after two weeks of classes. Again, the open-ended comments help us see deeper than the statistics alone:

“This class is enthusiastically taught and that enthusiasm is infectious. Also, I have always thought that circuits are very difficult to understand but the teaching of this course makes it seem easy and interesting at the same time.”

“The material is closer to "real-life" than I thought. I can use the things I'm learning right now.”

“The subject isn't interesting to me, but I would say making me neither interested or disinterested is an unexpected accomplishment.”

“The professor makes the material interesting in how it’s explained. Outside of that, the concepts itself would not keep my attention.”

These typical answers indicate the roots of success: real-life applications and enthusiasm of instructors (both the faculty and graduate students) help students learn and enjoy their learning of the new field.

A similar, but not identical, growth of student interest in the course material was found in the “summary” survey at the end of the semester, where we also asked questions focused on the future application of their learning of EE: see Table 4.

Table 4. The growth of student interest in the course material after taking the course
The numbers of respondents are in parentheses (total, 95)

	Extremely interested	Moderately interested	Neither interested nor disinterested	Moderately disinterested	Strongly disinterested
Before taking the course, how interested were you in learning the class material?	6.3% (6)	36.8% (35)	36.8% (35)	15.8% (15)	4.2% (4)
WHILE taking the course, how interested did you feel in the material it offered?	5.3% (5)	55.8% (53)	16.8% (16)	18.9% (18)	3.2% (3)
AS A RESULT OF LEARNING in this course, how interested are you in applying EE concepts, methods, and skills to your studies and work in your field of major?	15.8% (15)	52.6% (50)	17.9% (17)	8.4% (8)	5.3% (5)

Students’ comments help us understand what made their attitudes change after taking this course:

“I see how a lot of these concepts can be applied to other things, even in the field I’m working in which is not EE. The class made this more apparent, and I hope I can use these concepts in the future.”

“The material in the class has opened my eyes to the usefulness of EE topics in mechanical engineering, and has made me interested in learning more in applying these ideas.”

“This course really helped me to rediscover my interest in electrical physics and engineering. It made several concepts from Physics [pre-requisite course] more clear, and it introduced so many interesting and practical aspects of circuits.”

“My interest changed as I began to realize how widely applicable the information learned would be.”

As expected, Engineering majors are eager to learn useful, applicable things: convince them of usefulness of the material – and they start to appreciate their learning!

One of the students proudly announced to instructors that he switched his major to EE as a result of this course; another wrote that he/she “might take an EE minor now”.

- ***Has there been any singular event that sparked your interest or understanding of EE?***

We asked this question in the “one-third-of-the-way” survey, which was given after students completed 3 Labs and 4 HW assignments, before the first midterm exam. Out of 95 respondents, 56 answered “No” but among the rest we can easily identify the events that stemmed from the students’ learning experience in this course and those not directly related to the coursework.

Related to the coursework (the first response refers to the problem on electrostatic discharge and ways to avoid it; the other two responses refer to Lab 2, briefly outlined in the *Background* section above):

“I would say that the first homework, where we had to spend a long amount of time thinking, sparked my interest in EE because I enjoyed being pushed to think about some of ambiguous questions. Also, all of the labs have really been interesting to this point! MUCH better than a standard physics or math based lab (where you rush to do things in 2 hours but don't learn or care to remember anything).”

“The MOSFET lab with the photocell really sparked my interest.”

“The use of the MOSFET in the lab. I always understood how they worked, but it

was not until using them with the motor did I really understand how to use them in circuits.”

Not directly related to the coursework are the following interesting stories:

“My internship over the summer made me realize the importance of knowing EE information.”

“During a summer internship I was working on a scooter. I turned the key and it burst into flames. With hindsight it was very funny but at the time it was frightening and I was worried that I had done something wrong. I wanted to learn more about EE so I could avoid this in the future.”

“I was walking through some electronic gates that sense if you are taking a book from the library without checking it out and I had my headphones on. As I walked through I heard a high-pitched ringing and I realized it was my headphones picking up the signals from the gates.”

These stories are also valuable for the instructors: being retold in lecture/discussion, they might as well spark the interest of other students!

- ***What were the most interesting/valuable things that the students learned in this course?***

We asked this question in the “summary” survey at the end of the semester. It was an open-ended, essay-type question thus we present no statistics, only some typical answers.

“The most interesting things I learned were in the lab. Seeing how the theoretical concepts were applied in practical situations made more sense and was a great experience.”

“I liked the hands on lab work. It made me more confident in my ability to build working circuits that have useful functions.”

“The most interesting/valuable things I learned were related to the use of sensors in mechanical systems. I feel that these systems are necessary in all fields of engineering and it is important for everyone to understand them.”

“Mostly just helping to bridge the gap between understanding how every day electronics work. I know how to use a phone. I know what it does. With a little training I could probably write a program for one, too. But I never really understood how it works or why it works the way it does. Same with a computer. Instead of saying "oh, it's magic" I can say "oh, it does this."”

“The most interesting thing that I learned was in the final lab. By gaining

knowledge in different circuit elements throughout the semester, and then applying all of the learning in that one lab, it was quite interesting to see how much I had learned in a semester.”

“Learning about circuits gave me insight into a very important aspect of engineering that up until this point I knew little of. It rounded my engineering skill set to make me a better engineer.”

A summary of these answers provides a recipe for success: create interesting lab projects, make them relevant to non-EE fields, and emphasize that strategies and skills are transferable to a wide range of projects – and you will win the students’ hearts!

- *Future applications of student learning of EE*

In the “summary” survey we also asked: **“Which of the topics you studied in theory and hands-on skills you learned in EE Labs are most applicable to your major studies and work?”** It was an open-ended question; the following numbers show how many of the 95 respondents mentioned particular keywords:

- Circuit – 39
- Control – 29
- Op Amp – 14
- Filter – 9
- Program – 6
- MOSFET – 5
- Solder – 5

The open-ended answers spread over a surprisingly broad range, for example:

“I’d say it all is applicable. I’m in aerospace engineering and there is plenty of circuitry that goes into what I will be working with in the future.”

“Using sensors and controls are problem the most applicable to my major. I am a mechanical engineer.”

“Everything could be applied to my area of study. Understanding circuits is crucial for any engineer.”

“Nothing is too applicable thus far.”

Some of the students praised very simple things:

“The most applicable is the simple use to current and voltage laws.”

“Learning how to make circuits and use the tools to measure resistors and voltage was really useful.”

Others have much more advanced interests:

“Microprocessor programming and control circuits.”

“Active controllers and filters”

“I feel that the programmable controller is something which I will be using in the future in Mechanical Engineering. Additionally, I feel amplifiers will be something that I can apply to designs.”

Several students seem to have pretty clear ideas of what they need, like and will use:

“Fourier analysis and frequency spectrums were the most applicable theoretical concepts to nuclear engineering. As for hands on skills, building circuits might not be necessary for my future applications, but measuring the behavior of circuits will be applicable to certain procedures in Nuclear Engineering labs.”

“The lab and hands on skills is the most applicable to my major studies, because knowing how to build circuits is important for medical devices.”

“Analog/Digital Conversion along with sensors are the most applicable things.”

“I have to build circuits for the mechatronics section of my [other] class and learning how to build them properly helped me.”

“Controls work will use a lot of filters, these were the most fun and interesting in my opinion.”

Some others still do not know what they might need:

“No idea. I hate this question. This is my first semester in my major and I have no idea where EECS ties in with my major...”

“I can't recall any skills/theory that I can apply to my major studies and work.”

Reading these responses helps everyone envision and appreciate the diversity of this class. For an instructor, it creates a challenge and presents an opportunity: finding examples of applications to various fields of engineering might evoke interest of students who lack motivation to learn EE.

We also asked: **“How exactly are you going to apply your learning [of EE] to your major studies and work? In particular, to which of your major courses does it relate?”**

The answers of many students are very enthusiastic; out of 79 respondents, only 14 did not know how to apply their learning. (The answer to this question was not required thus

16 students skipped it.) Here are some typical responses:

“I can greatly use the knowledge I gained in mechatronics to wire and make circuits.”

“It relates to a bioinstrumentation class that I have to take.”

“I will know how to build circuits and control systems for Mechanical Engineering Design courses.”

“This class relates to ME [control course] and future design courses. I should now be more qualified to analyze and build working systems.”

“Sensors such a strain gauges relate perfectly to coursework in aerospace structures. Other sensors and signal conversion relate to the field of dynamics and controls of aerospace systems.”

“As an aerospace engineer, application for EE could either be very high or very low depending on what kind of job I get. I could be doing a lot of wiring, soldering, programming, etc., or I might be working in wind tunnels where application may not be as high (although using sensors in a wind tunnel may be applicable).”

- ***Scheduling homework (HW) before the Labs***

One of our most unexpected findings (made in the “one-third-of-the-way” survey, which was given after students completed 3 Labs and 4 HW assignments, before the first midterm exam) was the strong preference expressed by students to have new concepts first explained then observed in the lab: see Table 5.

Table 5. The students’ preferences of how the Labs and HW should be scheduled
The numbers of respondents are in parentheses (total, 95 to 98)

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
First learn the theory in lectures and homework, then do the lab	41.8% (41)	43.9% (43)	8.2% (8)	4.1% (4)	2.0% (2)
First observe something new in the lab, then learn the theory	2.1% (2)	16.5% (16)	26.8% (26)	39.2% (38)	15.5% (15)
Learn the theory (do the homework) and do the lab at the same time	8.2% (8)	25.5% (25)	27.6% (27)	27.6% (27)	11.2% (11)
The exact sequence does not matter	7.4% (7)	9.5% (9)	38.9% (37)	25.3% (24)	18.9% (18)

Table 5 shows that students in this introductory course do *not* appreciate any “discoveries” or unexpected/unexplained observations in the lab: instead, they strongly prefer Lab experiments to reinforce the theory. Although such sequence is opposite of how the science/engineering develops, it makes a lot of sense in the educational setting, especially, in a class for non-majors who are taking their first course in an unfamiliar field and do not have enough background knowledge for discovery-based learning.

Students themselves explain:

“To truly understand what I am doing in lab, I need to understand the material first. It is pointless for me to go to lab not knowing what is going on because I will just be confused.”

“You need the concepts introduced to you, and have had practice with them to increase your understanding a bit before actually applying it to a real life situation in the lab.”

“Having a clear idea of the concepts before a lab is always an asset. Doing the reverse or learning them at the same time just makes it harder to relate the topics to one another.”

This strong preference of students should be taken into account for scheduling the course. In Fall 2012, we promptly followed this guidance.

- ***Balancing the workload between labs and homework assignments***

In the “summary” survey we asked: **“How do you estimate the actual and the desired time balance between weekly theory-related and lab-related coursework in this course?”**

Table 6. The students’ preferences of balancing the workload between Labs and HW
The numbers of respondents are in parentheses (total, 87 to 89)

	20% theory / 80% Lab	35% theory / 65% Lab	50% theory / 50% Lab	65% theory / 35% Lab	80% theory / 20% Lab
Actual time balance	9.0% (8)	16.9% (15)	27.0% (24)	34.8% (31)	12.4% (11)
Desired time balance	3.4% (3)	19.5% (17)	54.0% (47)	17.2% (15)	5.7% (5)

It is interesting to see that the desired time balance, according to the students’ preferences, is a symmetric “curve” centered at 50:50 theory/Lab, while the actual time balance is skewed toward 65:35 theory/Lab. Trying to shift this balance toward 50:50

means that during Lab weeks the homework load should be lightened, which presents a certain challenge, because lectures and HW should cover new concepts for future Labs.

The drawbacks in this course, which became obvious from students' responses to several surveys, include:

- The total workload was too heavy, especially in some HW assignments
- In some Labs, the scheduled time was not enough to complete the in-lab work
- Some of Pre-Labs were too closely related to HW and seemed to be busy work

To eliminate these drawbacks is our goal for the near future.

We believe that collecting similar feedback in other courses would help all instructors to balance the workload in individual courses as well as in the “packets” of courses that students usually take during the same semester. Such information, available on a regular basis, would also help academic advisors to recommend appropriate combinations of courses to students of various major fields.

- *Students' perceptions of the multi-disciplinary learning environment*

In the “summary” survey at the end of Fall 2012, we asked the following open-ended question: **“By taking this course, you have crossed the boundaries of engineering disciplines. How comfortable have you been in this multi-disciplinary environment? How does it compare with your other multi-disciplinary experiences?”**

Not surprisingly, the students' answers (94 respondents) reflect the diversity of their experiences and interests. Many of them were optimistic and positive, for example:

“I was nervous about this class, but it taught me to be more comfortable with that kind of environment, which is great.”

“I have been fairly comfortable. Sometimes it was hard to think differently, but overall I learned a lot and enjoyed my experience. I liked working with others from other engineering disciplines, and it was nice to be able to understand the concepts and work through practice problems together.”

“I have been very comfortable crossing into a different type of Engineering. I like this experience because it is a class made for non-EE majors. The professor realizes we are not particularly interested in Electrical Engineering and he tries to apply it to all types of Engineering. Most of the other classes I have taken in other departments do not try to apply it to all fields of Engineering.”

Some students compared this course to their previous multi-disciplinary experiences:

“Multi-disciplinary is the best way to learn engineering in my opinion. This was more theory based than my other multidisciplinary projects.”

“My main multi-disciplinary experience is doing aerodynamics with the solar car team. I work very closely with mechanical engineers on the solar car team, but this is my first experience with the electrical side. I do feel very comfortable with it though.”

“I like multi-disciplinary education. It is different from my other multi-disciplinary experiences because my other experiences of that type were more business-related; I haven't really applied other types of engineering to projects, at least not in the same depth as we went into EE this semester.”

For others, this was new:

“I have been quite comfortable; I quickly grasped most concepts taught in this course. I have not been involved in other multi-disciplinary experiences.”

“I don't have too much experience working with other multi-disciplinary design programs, but I really enjoyed the experience, and I felt very comfortable both learning and applying the material presented.”

“I normally work with structures so working on the electrical side of things for once was a bit different but I can see why it is an enjoyable subject as creating components can be extremely gratifying.”

Not all students were convinced of the usefulness of multi-disciplinary experience but such responses are few and far between (the quotes below show them all):

“I am not comfortable. I don't think I will ever have to use EE.”

“This is my first multi-disciplinary experience (other than taking entry level classes). I didn't like it very much, but that's mainly because I have no interesting in electrical engineering whatsoever, so if I was not required to take this course, this would have been near the bottom of my interests in other fields.”

“Too early to say.”

Overall, we strongly believe that the course reaches its goal: it opens new horizons to non-EE majors and makes them willing to apply EE to their fields of studies and work. Quoting another student's response:

“I enjoyed being able to learn about EE and it opened up possibilities for interdisciplinary work in the future.”

In the “summary” survey at the end of Fall 2012, we also asked the following open-ended question: **“Have you gained in this course any experiences that would be useful for future work in multi-disciplinary engineering teams?”**

Again, the answers (61 respondents) were mostly positive. We found only 8 negative answers such as “No,” “Not really” or “None” (13%).

Some students emphasize their communication skills:

“Being sociable and easy to work with.”

“I learned good team skills in the labs.”

“How to work on a lab with someone well.”

Others sound more professional:

“Yes, I have gained a much greater general knowledge of EE and how it links to ME on a functional level.”

“I will be able to understand more of what the people who are focusing on the electronics are doing.”

“Yes. I can see thru their shoes now and can understand their jargon.”

However, professionalism and people skills do not contradict each other:

“Yes, all of the lab experience is very useful for hands on experience and knowing new tricks. Also, working with a partner is always helpful in learning different dynamics and how to get the job done with different types of people and with different projects at hand.”

“Being able to participate in conversations on all sides of the design process makes for an efficient and effective engineer, especially when it comes to mechanical and electrical. Work with integrated circuits and filters was particularly useful.”

“Yes, I understand the basics of circuitry which will be helpful if I ever need to work with EE students.”

Several responses outline specific goals for the near future:

“Yes, I can suggest circuitry and sensors to my project teams which are mostly mechanical people.”

“Yes. When working with multi-disciplinary teams, I feel confident that I can take on the role of an Electrical engineer in some applications. For example, I feel confident that I would be able to build a circuit that could measure the heat given off by a combustion engine (creating combustion engines require many different engineering disciplines).”

“Yes my project next semester is closely related to electrical engineering.”

“Yes, everything we learned will be useful for control systems.”

Others are very general:

“Yes. Knowledge of basic electrical engineering concepts is very important in a career in aerospace engineering.”

“Technology is so reliant on electronics, having taken this class I feel much more prepared to take on many different engineering feats.”

In hindsight, students realize the usefulness of EE learning for their past projects:

“Yes. Simply learning more about electrical circuits would have helped a lot when I was on the Formula Hybrid team.”

“I took a lab last year where circuit building and soldering would've been very useful. If I'm going to be putting together flight systems, I'm going to need to be able to wire things.”

Also, students realize that entering a new field and mastering it are different things:

“My new understanding of electronics helps me understand what the electrical engineers in my project do, thus making me more capable of communicating my ideas to them.”

“Possibly a better knowledge of circuit design, but probably not too easy to actually use it.”

“I learned that I will need an electrical engineer on my team in the future because I still don't really understand it...”

- *Advice to future students*

Last but not least, we asked in the “summary” survey: “Any advice to the students who will take this course in the future?” Some of the students’ answers are focused on time management and other details of the course; we convey this advice to new students by attaching the wisest and wittiest statements to the syllabus. Of greater interest here is the student feedback that shows the wider perspective:

“Take this course before solid mechanics, dynamics, and structures.”

“Take this course before taking “Elements of Nuclear Engineering and

Radiological Sciences” and the math course in partial differential equations in Nuclear Engineering. The concepts learned in this course will help put you in the mindset of being an engineer, and concepts learned in more advanced courses may come easier after taking this course. Spend time on learning the skills taught in lab! Many other labs will require you to apply some of these skills.”

“I would recommend taking this course at the same time as “Modeling, Analysis and Control of Dynamic Systems” in Mechanical Engineering because the topics covered ran almost parallel for the entire semester.” (Advice by several students.)

“Take this course before taking ME courses in Design and Manufacturing.” (Several students repeat this advice; some recommend taking the courses concurrently.)

These responses demonstrate that students are actively thinking about how the “different” fields of engineering are indeed inter-related, and how the knowledge gained in one field can enhance their learning in other fields. Also, the responses from students who regret that they did not take this course earlier indicate the growth of their appreciation of the value of EE for their professional development.

Conclusions

The results reported here reveal the evolution of students’ perception of the value of EE for their non-EE fields of major, indicate what caused the growth of their interest in EE, demonstrate their appreciation of inter-disciplinary learning, and show the development of a broader view of engineering as inter-related fields.

Some of our findings may serve as recipe for success for other service courses:

- ✓ The focus on real-life applications and enthusiasm of instructors (both the faculty and graduate students) help students learn and enjoy their learning of the new field.
 - *Which parts* of the material the students perceive as applicable to “real life” depends on the students’ views (beauty is in the eye of the beholder). Instructors who teach other service courses may survey *their* students to find out what they find valuable in the particular course; these responses may vary by the students’ field of major.
 - Here are some particular suggestions (based on our teaching practice) for EE courses offered to non-EE majors. Emphasize that nowadays nearly all measurements are done with electronic instruments – and ask the students to list the experimental parameters, which *they* are going to measure in their projects. Analyze the list, which may be very long (position, velocity, acceleration, force, temperature, flow rate, etc.) and choose examples of sensors and particular applications focused on the specific parameters. Explicit references such as “this is how you can

measure the flow rate” will definitely awaken students’ attention in lectures. Create homework problems that include manufacturer’s data on sensors and formulate them in terms of the applications, for example: “design an amplifier circuit such that the output voltage equals zero at zero pressure and equals 10 V at 25 psi.”

- Enthusiasm is a learned behavior⁵. It is not “given” that *every* instructor possesses it, especially a graduate student who teaches lab sections and leads discussions in a large service course. It is the responsibility of the principal instructor to develop his/her own enthusiasm and to foster the enthusiasm of graduate student instructors. Again, objective surveys can reveal whether the students feel the enthusiasm of their instructors.
- ✓ Engineering majors are eager to learn useful, applicable things: convince them of usefulness of the material – and they start to appreciate their learning!
 - In a large, diverse service course the usefulness of any material may be perceived differently by students with different majors: for example, what is useful for mechanical engineers interested in mechatronics might seem useless for industrial and operations engineers who focus on profitable business practices. It is the art of the instructor to find examples and applications of the course material that would resonate with students from all fields of engineering.
- ✓ Create interesting lab projects, make them relevant to non-EE fields, emphasize that strategies and skills are transferable to a wide range of projects – and you will win the students’ hearts!
 - For example, when our students do the temperature controller lab, we emphasize that a similar electronic circuit and control strategy can be used with other resistive sensors (for strain/stress, light intensity, etc.) and with other actuators; therefore their learning in this course is transferable to many projects in many fields of engineering.

Future development

In this report we detected the sparks of students’ interest and traced them to the particular components of the course (mostly, the lab experiments) as well as the specific topics discussed in lectures and practiced in homework, but we could not reveal whether the interest expressed by individual students led to sustained motivation and fostered their successful learning of the course material and its application to their fields of major.

These are the topics of our future research. We plan to conduct a longitudinal study using the tools that would allow us to identify the *responses of an individual student to several surveys*, while maintaining anonymity of each respondent. Our future goals include: (a) Link the growth of students’ interest in the subject material to their motivation and actual progress of learning; (b) Group the students’ responses according to their fields of major in order to identify the common trends; (c) Reveal the connection between the students’ learning in this course and their success in further courses and work in their fields of major.

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