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Development of student motivation in a required Electrical Engineering (EE) course for non-EE majors

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Every instructor who has taught a required course outside the students' field of major knows that the main challenge is to overcome their lack of interest in the course material and lack of motivation to learn and apply this material to their future studies and work. Despite this pessimistic background, the authors propose the following working hypotheses and apply them to a large service course in Electrical Engineering (EE) for non-EE engineering majors.

The working hypotheses:

1. Non-EE engineering students who are taking a required EE course can develop interest in EE, become motivated and confident to apply EE to their fields of major.
2. Researchers can identify what teaching events and/or components of the course foster students' interest and motivation.
3. Researchers can find out what parts of the course material the students see as valuable, applicable to their fields of engineering.

This research team, which includes professionals from the College of Engineering and the School of Education, has applied quantitative and qualitative methods for longitudinal research of students' learning during Fall 2013 semester, and enjoyed a remarkably high participation: practically every student enrolled in the course has responded to at least one survey, and 110 out of ~190 enrolled students responded to all 4 surveys. Besides large statistics, the authors collected open-ended responses of students to many questions, which reveal the development of their motivation and the pivotal points, which influenced this development. Since the rich results have been just collected, the scope of this report is limited to the most striking data.

For example:

- ✓ 69% of 170 respondents agree or strongly agree with the statement "The course material has been interesting to me."
- ✓ 70% (of 170) non-EE students are satisfied or very satisfied with this EE course
- ✓ 55% (of 153) students report increased interest in EE due to taking this course
- ✓ 62% (of 153) non-EE students report increased motivation to apply EE to their fields
- ✓ 79% (of 153) non-EE students report increased confidence in applying EE to their fields.

The authors anticipate several types of applications for their findings:

A. Fine-tuning of the teaching strategies and the logistics in this course.
B. Verification of these findings in the future semesters (with different student demographics, etc.)
C. Dissemination of successful teaching strategies, logistics, and course materials to other schools who teach EE to non-EE engineering students
D. Some of the strategies and logistic elements can be transferable to service courses in other engineering disciplines.

The structure of this report[1]

This report begins with the main findings and conclusions, which may be of interest for the largest reading audience. Then, student demographics and the course structure/logistics are presented. A brief review of literature provides the theoretical foundation for the research methods, which are explained for the most interested readers. Finally, a plan is outlined for future studies.

Main findings and conclusions

Figure 1 shows some results of our midterm survey, which was given to students after ~2 months in a standard 14-week semester.

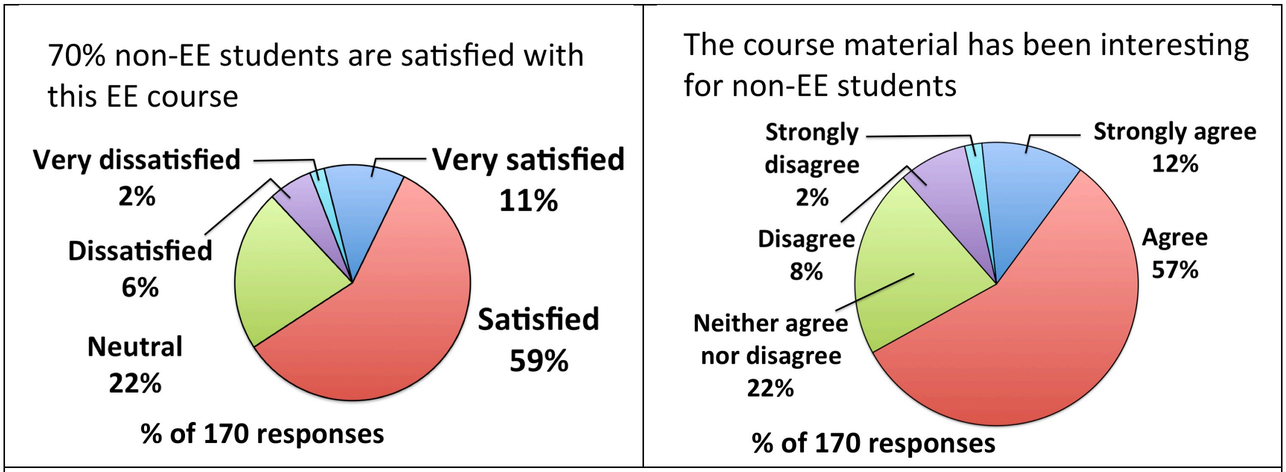


Figure 1.

The midterm survey results reveal high student satisfaction and interest in the course material.

The class includes engineering students from several departments (see the details in *Course demographics* below), some of which require the EE course as pre-requisite for their major courses, while others merely list it as a graduation requirement or elective. Therefore, diversity of the student responses to survey questions is not surprising at all. Nevertheless, over two thirds of the class are satisfied with the course and interested in the material being studied.

Figure 2 presents some of the students' responses to the final survey, which was given after the last lecture, with the closing time before the final exam.

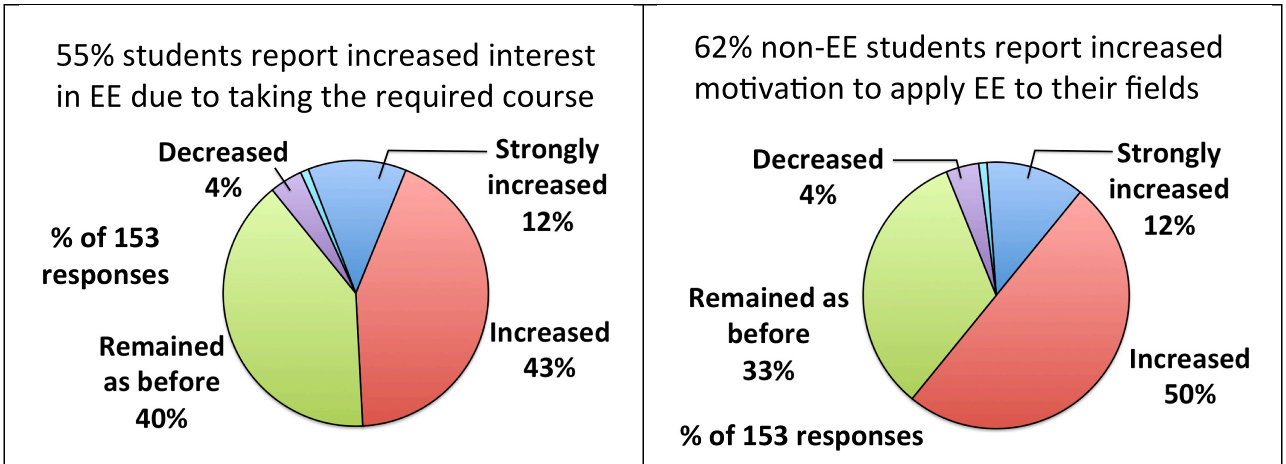
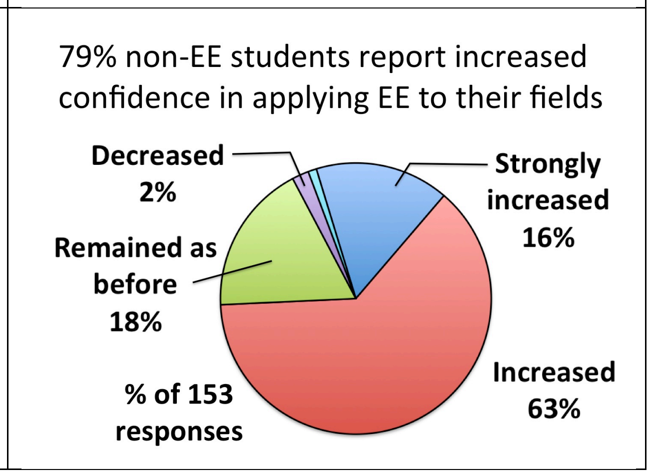


Figure 2.

The responses of non-EE students to the final survey emphasize significant growth of: (a) their interest in EE, (b) motivation to apply EE to their fields of major, and (c) the highest increase of their confidence in applying EE to their engineering fields.



Due to taking this course for non-EE majors, students report an increase in three key aspects:

- ✓ Interest in the course material
- ✓ Motivation to apply their learning of EE to non-EE engineering fields
- ✓ Confidence that they can apply EE to their fields of major.

Noteworthy, the growth of motivation and, especially, the growth of confidence are most significant.

Thus, the first working hypothesis (see the very beginning of this report) has been confirmed:

> Non-EE engineering students who are taking a required EE course can get interested in EE, become motivated and confident to apply EE to their fields of major.

The authors also address the second working hypothesis: Can one identify what teaching events and/or components of the course foster students' interest and motivation?

Figure 3 presents the summary of students' answers to the following open-ended questions in the final survey:

- ✓ "My most positive experience in this course has been..." (left panel)
- ✓ "Please list or rank the top 3-5 course resources that influenced your interest and motivation to learn/apply electrical engineering to your field" (right panel).

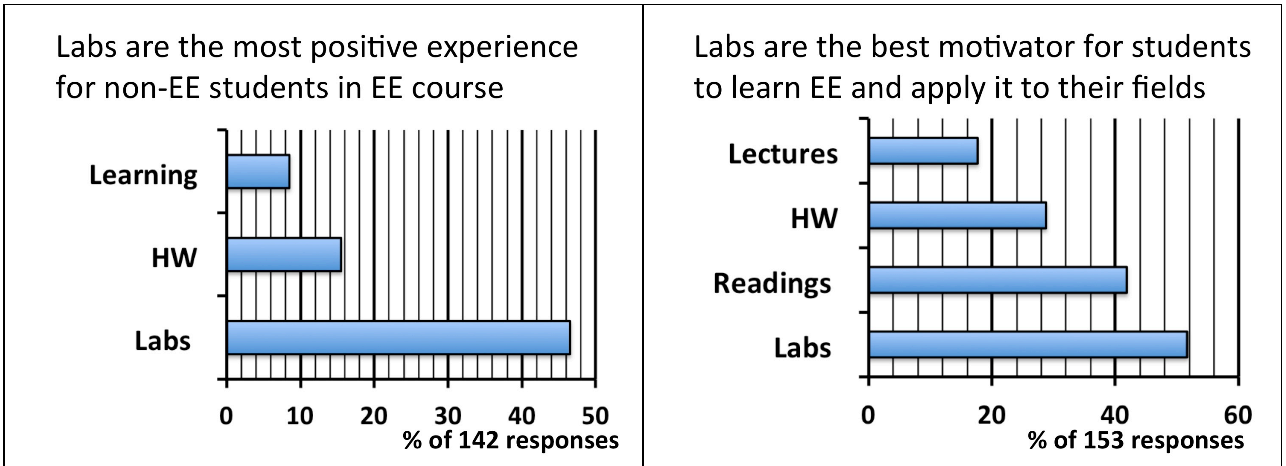


Figure 3.

The responses of non-EE students to our final survey highlight the Labs as the most positive experience in this EE course and the most influential motivator to learn EE and apply it to their fields of major. In the left panel, the top entry belongs to “Learning new concepts”; in the right panel “Readings” mean the required chapters, assigned weekly for particular homework (HW).

As expected in a diverse class, the respondents listed many particulars, such as:

- ✓ “Working on HW with friends”
- ✓ “Doing a HW completely by myself”
- ✓ “Learning useful material”
- ✓ “Completing the HW, in essence applying my knowledge of EE to a real world problem.”

Nevertheless, hands-on experience in the Labs is the absolute leader in both positive experience and motivation to learn/apply EE to non-EE fields.

Students’ answers to open-ended questions provide valuable insight:

- ✓ “Seeing real world examples and hands on stuff kept me interested. When I could see how to apply it, I was riveted.”
- ✓ “Learning to use photoresistors to position satellites towards the sun sparked my imagination.”
- ✓ “I expected this course to be much more abstract, and I expected to be learning about circuits that wouldn't be applicable to my major. I think the second homework, with the problem about calibration of resistive sensors really piqued my interest. Even something as simple as a voltage divider with a variable resistor, and it was presented in a context that would be useful in mechanical engineering.”

In the first approximation, one may say that engineering students are simply pragmatic: learning about a voltage divider does not seem interesting unless it applies to sensor circuits, which they plan to use in the future. This is certainly true.

Moreover, this is a strategy, which applies across many course components. Students' responses refer to lectures and demonstrations of lab experiments, to reading materials and informal talks with the course instructors, to doing homework (which was not expected by the researchers) and solving practice exam problems (which was also unexpected).

The take-home message for the instructor is straightforward:

> Avoid talking about EE as an abstract field: make sure that each concept is "presented in a context that would be useful" (quote from the student's statement above) – and the sparks of interest will start flying in your classroom and in your lab.

Of course, doing the labs is extremely important. More quotes from the students:

- ✓ "The labs definitely increased my interest because it was practical and I realized how much I could do with my gained knowledge."
- ✓ "The few programming aspects of labs along with the more applied labs influenced my interest."
- ✓ "The last lab increased my interest because it showed how EE could be directly tied to mechanical systems by analyzing temperature changes."

Thus the next advice to the instructor is:

> Include the labs in your course, and focus them on applications of EE to non-EE fields.

More broadly (or deeply), the students' vision of interdependence among engineering disciplines has also evolved:

- ✓ "I never thought circuit analysis would be useful for an aerospace engineer. Once I realized that airplanes, cars, and pretty much any other mechanical vehicle nowadays is just a giant computer, I realized that the importance of electrical engineering in my field."
- ✓ "I would say that before [taking this course], I knew all of these things existed and were important to ME but now it's as if a blanket was lifted and now my eyes have been opened to how the things I knew always existed actually work and function (regarding energy and power and safety).
- ✓ "Yes, my view has changed very much; I had friends (upper classmen) tell me that EE involved lots of MOSFETs and logic circuits. I knew a MOSFET was a type of transistor, but I didn't really know what its implications or uses were. [Their] comments about logic circuits made me expect that [this course] covered mostly theory, especially integrated circuits with lots of logic gates, and I was expecting a very abstract class. I think the lectures of new material which included demos or example videos help change my mind about the applications of this class. Nearly all new material was presented in a way that I found useful to my major, such as the first few labs dealing with MOSFETs, as well as the last few lectures and final lab dealing with Wheatstone bridges and sensors, controls, etc."

Even the students from Industrial and Operation Engineering, for whom this course is elective, have found interesting/valuable aspects of EE:

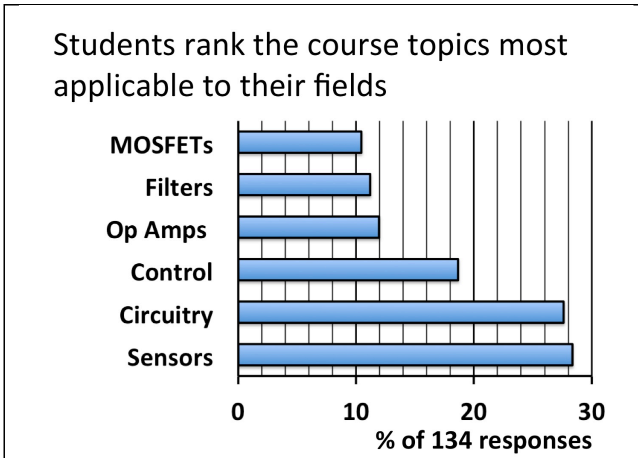
- ✓ "Circuits in general, since they apply to the many products that IOE majors help ship and process."

- ✓ Labs did this [motivation] for me and now I am looking into EE related jobs in the field of IOE."
- ✓ "Yes. I thought that I wouldn't be able to apply anything to my major field. Now, I realize that one thing I can apply are truth tables, even in a non circuit related sense. Going into IOE a lot of my work is about optimization and I believe truth tables can help me work towards that goal."

The conclusion for the instructor:

> Do *not* to assume that you know *what* your students find interesting: instead, ask them directly. Motivation depends on many factors (see the *Literature review* below), most of which are beyond the instructor's control. Create and conduct surveys to find out what motivates the students in your class, and foster their interests to help them learn. For achieving these goals surveys are invaluable; they do help teach and improve the course.

Finally, the survey results allow the authors to address the third working hypothesis: Find out what parts of the course material the students see as valuable, applicable to their fields of engineering. Figure 4 summarizes their open-ended answers to questions of the final survey.



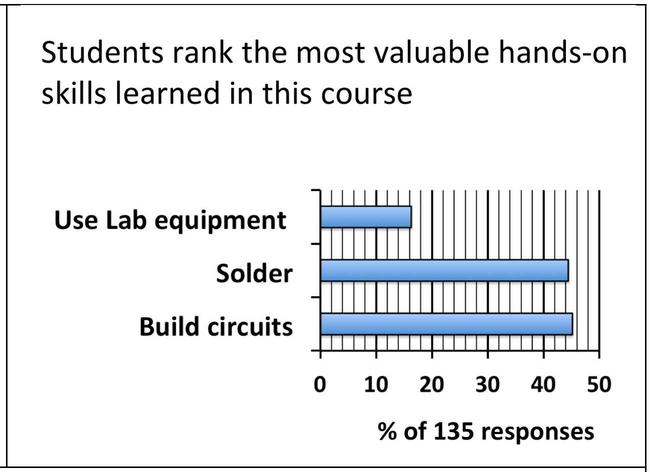


Figure 4.

Students' responses to the final survey are focused on the few topics most applicable to their fields of major (left panel); here "Circuitry" embraces building, analyzing, and varying the output of the circuits. Students' ranking of hands-on skills (right panel) emphasizes circuit building on solderless prototyping boards along with soldering; learning to use modern lab equipment is also valuable.

The students' answers on applicability of the course material vary from "I think every topic is applicable to my field" to "I do not see how I will apply this learning." This is not surprising and might directly relate to various types of motivation (see the *Literature review*). From the broad range of course topics (see the *Course structure/logistics* below) students focus those, about which they already heard from their advisors and upperclassmen (external motivation), as well as the topics, which stem from their own interests (internal motivation).

External motivation is easy to detect, for instance, in the statement about the value of "building circuits. Practical circuit building is liked by employers." Internal motivation most likely defines the positive learning experience of "Being able to truly understand the concepts and figure out for myself how they can be applied in the real world."

It is much harder to identify how internal and external motivations intertwine in statements such as "Electronics are prevalent in all industries and knowledge about electrical engineering is a must for any engineer" or "I really enjoyed the extra credit readings." As in many other real-world situations, enjoyment from reading might overlap with joy for earning extra credit, and it would be unwise to discard any of these.

More wisely, it seems, would be to find ways to present the course material so that *both* internal and external motivations help students get "riveted" (as the student wrote) and start learning. Pedagogically, this requires a strong connection between each theoretical concept and its practical application.

In the context of this course, the surveys suggest ways for improvement; for example, ensure that Nuclear Engineering students feel more engaged in the material (so far, their responses show comparatively little interest).

Course demographics

Figure 5 presents the course demographics according to the official roster.

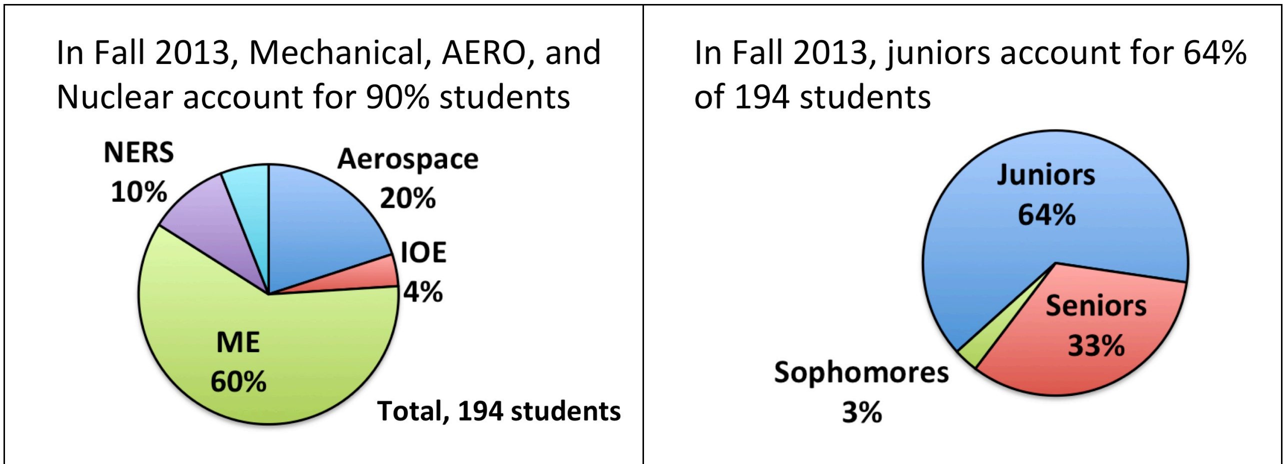


Figure 5.

The course demographics for the semester under study. In the left panel, the sector without label includes: Engineering Physics, Materials Science, Biomedical Engineering, unclassified undergraduate engineering, and other undeclared majors.

The demographic data shown in Figure 5 are typical for this course. Enrollment of ~190 has been the course average for several years; also, Mechanical Engineering students constitute the major part of class in every semester. On the other hand, due to their curricular changes, the percentages of students from particular departments vary from the Fall to Winter or Spring terms.

The number of sophomores taking the course is likely to increase in the near future because the advantages of taking this course earlier in the curriculum is being recognized by students and advisors alike.

Course structure/logistics

This 4-credit, one-semester course includes lectures, discussions, and labs. A typical weekly load includes 3 hours of lectures (one section), 1 hour of discussion (4 sections, approx. 50 students each), and 2 hours of in-lab work (sections up to 18 students each). Homework is assigned weekly, except of the weeks of midterm exams. Office hours are held by all instructors on both HW and lab material.

Over the 14-week semester, every student completes 8 lab projects, each including pre-lab, in-lab, and post-lab parts. Labs begin on the 3rd week of classes, to ensure that students learn enough theory before applying it; there are no labs on midterm exam weeks and on the last week of classes.

Two midterm exams and the final exam are in multiple-choice format; sets of practice problems (taken from exams of previous semesters) are given before each exam. Exam problems cover homework and lab material; each exam includes qualitative questions and numerical/algebraic calculations.

Literature review

Motivation is a concept with a wide variety of definitions across many different fields. Ryan and Deci[2] state that, despite the fact that motivation is often discussed as one concept, the theories of motivation suggest a multitude of factors that might affect an individual's desire to perform well given an activity or set of tasks. Examples of these different types of motivation are present in the author's classroom environments. For example, when students are asked what motivates them to perform well in a course, responses could vary from "my advisor told me I had to pass this class to move forward in my coursework," to "I am sincerely interested in the field of electrical engineering and want to enhance my knowledge of the subject." These different types of motivation are discussed by Ryan and Deci[2] as the differences between intrinsic and extrinsic motivation.

According to Ryan and Deci[2], "the term extrinsic motivation refers to the performance of an activity in order to attain some separable outcome and, thus, contrasts with intrinsic motivation, which refers to doing an activity for the inherent satisfaction of the activity itself" (p.71). Extrinsic motivation can also be further broken down into four regulatory styles. In external regulation, students merely complete tasks to comply with the requests of an authority or to gain rewards or avoid punishment. Introjected regulation involves taking on a task, but not fully accepting it as one's own choice. In this form of regulation, individuals may comply with external requests to maintain their own self-esteem (i.e. avoid guilt or anxiety). The third form of extrinsic motivation is known as identified regulation. In this form, individuals begin to view a task as personally important to their goals, but these goals might still be extrinsically motivated (i.e. I have to make a certain grade to boost my GPA because this is how future employers might view my potential success). Finally, integrated regulation arises when projects or task come into agreement with an individual's values or needs. Although this form of extrinsic motivation may appear to be intrinsic in nature, Ryan and Deci note that, "actions characterized by integrated motivation share many qualities with intrinsic motivation, although they are still considered extrinsic because they are done to attain separable outcomes rather than for their inherent enjoyment" (p.73).

For example, the students who are motivated because their advisors told them to take the course would be viewed as having an extrinsic type of motivation (attaining a separable outcome), whereas the students who are genuinely interested in the subject would be considered as having an intrinsic motivation style (the inherent satisfaction of learning electrical engineering). Although either form of motivation (extrinsic or intrinsic) can be particularly important to the success of a student in the classroom, researchers explain that a student's intrinsic motivation has the greatest effect on his or her potential to genuinely enjoy activities and careers, expand knowledge, and seek out new challenges[2, 3, 4].

While research has proven that grades and other external structures can motivate students to perform well in classrooms[5, 6], the authors of this report examine extrinsic and intrinsic motivations and their effects on students' performance in this class. Pintrich[7] points to five general constructs in understanding the motivations of students in the classroom. Additionally, he offers suggestions as to how classroom instruction might be designed to encourage student motivation.

First, Pintrich[7] notes that courses should be designed to encourage self-efficacy and confidence in being successful in the class. Students should feel confident upon entering the course that they can be successful given the challenges of the curriculum. Initial feelings of incompetency or inability to perform the coursework can be detrimental to students' motivation to succeed in the course. In this regard, students should receive equal parts challenge and support in the classroom, so that they feel adequately tested in the course, but without feelings of hopelessness to perform well.

Second, students should feel that they are able to control their own success in the classroom. This can be achieved by allowing several different opportunities for students to practice course concepts using a variety of instructional methods. For example, some students may enjoy opportunities to reinforce course topics through hands-on learning, such as what would be found in classroom laboratories. Others might benefit more from practice problems that allow them to reinforce course topics through problem solving. Providing a plentiful variety of choices benefits students in picking and choosing how they might best learn course concepts[7].

Third, course concepts should be designed to encourage interest, and thus, stimulate intrinsic motivation among students. Providing course materials and activities that are applicable and meaningful to students' future coursework and/or careers encourages students to become interested in course topics because they are closely related to future goals. Fourth, students should feel as if course material is valuable to them. Allowing for students to utilize course material or imagine how they might use it in the future shows them the necessity to master course concepts and apply course objectives to future work. Finally, students, as individuals or within groups, should be allowed to set goals for their expectations of the course. Asking students what they wish to get out of the course and how they might plan to use course topics in the future helps them to prioritize the importance of succeeding in the class[7].

The studies of motivation were developed and applied in social sciences; their applications to Engineering Education are very rare (the authors would be grateful to readers for references to work beyond the scope of our knowledge). Gero[20] was one of the first researchers of student motivation in an Electrical Engineering course who used quantitative and qualitative methods, employed validated surveys that differentiate between intrinsic motivation and the four regulations of extrinsic motivation, and focused on a project-oriented Electrical Engineering course. Significant distinctions of the study presented here from the context of Gero's research[20] include:

- ✓ The nature and the size of the course (Gero[20] studied an elective course of 25 students, which is difficult to compare with a required course of ~200 students reported here)
- ✓ The demographics of the student body (Gero[20] studied a course for EE majors while the present work is focused on a service EE course for non-EE majors)
- ✓ The hands-on experiences of students in two courses (the course studied by Gero[20] did not include any hands-on labs; the students focused on search of information, selection of components, and preparing the final presentation, but they *did not build* anything; on the contrary, in the course reported here, it was the hands-on experience of students in the lab that produced the greatest effect on their interest, motivation, and confidence).

Utilizing Pintrich's instructional design recommendations for enhancing motivation[7], the study presented here takes an exploratory approach to understanding how such instructional methods will motivate students to succeed in a non-major course. The nature of this study is exploratory: the goal is to further understand the nature of what instructional practices or course materials enhance interest in electrical engineering topics with the intent to specifically examine these practices or events in future studies. The authors also anticipate that such findings will be applicable to other instructors teaching topics to non-major students in other engineering fields at other institutions.

Research methods

This study utilized four surveys throughout the course of the fall semester of 2013 that each specifically measured how students' background characteristics and instructional techniques used during the course enhanced motivation and interest in course concepts. In implementing surveys throughout the semester, the authors aspired to examine how students' motivation and interest changed (either positively or negatively) from the beginning to the end of the course, and discover any specific events or experiences attributed to these changes. All surveys were implemented via online questionnaires where students were given 1-2 weeks to complete the survey during on their own time. Students were identified and student responses were validated by requiring students to submit campus usernames with each survey and only allowing enrolled students to complete surveys.

The first survey was administered before the first class of the semester. This survey served to gain an understanding of the background characteristics and experiences of the incoming students in the course. Additionally, the authors hoped to understand what learning strategies motivated students to perform well in courses. First, students completed 18 questions adapted from the Motivated Strategies for Learning Questionnaire[8]. The Motivated Strategies for Learning Questionnaire is an empirically-validated student questionnaire used to measure "student motivation, cognitive strategy use, metacognitive strategy use, and management of effort" (p. 34). Next, students were asked questions about previous experiences working with electrical engineering concepts ("Discuss your previous experience with topics in electrical engineering"), and expectations regarding how they felt the course should be designed ("In order to be successful in a lecture/theory and hands-on/lab-based course, I prefer that my courses are balanced in the following way") and how they envisioned the course fulfilling being applied back to their major field.

The second survey was conducted during the first two weeks of class and focused on the type of motivation (intrinsic or extrinsic) students had to enroll in and perform well in this course and what course topics were most applicable to their studies. Students completed 16 questions (adapted from the Intrinsic Motivation Inventory[9 – 14]) used to assess students' interest/enjoyment, perceived competence, effort, value/usefulness, pressures/tensions, and perceived choices in performing a task or set of tasks in a classroom environment. Next, students were asked to identify course topics that were most applicable and of greatest interest to them from a list of commonly addressed topics throughout the course.

The third and fourth surveys were implemented mid-way and at the end of the semester, respectively, and measured course satisfaction and instructional strategies that most benefited students at mid-way and final points. The purpose of these two surveys was two-fold. The first purpose was to measure how students' interests in courses topics had evolved throughout the semester. The second purpose was to determine if there were any specific events or instructional techniques that affected this interest.

In hindsight, the present study could be improved by the use of exactly the same wording of questions in subsequent surveys, because the respondents might interpret the slight variations in several ways. This is one of the immediate goals for the future research.

Further research

The authors strongly believe that this research is among the first applications of longitudinal analysis, combining quantitative and qualitative methods, to Engineering Education. Any literature search reveals scarcity of research on motivation of engineering students, especially, non-majors who take required courses with significant laboratory component[15 – 20]. Even further limited is the research that specifically deals with the distinction between intrinsic and extrinsic motivation.

This study also fills an important gap. Even the best and most popular books on teaching say almost nothing about development of engineering courses for non-majors, about motivation of students in the lab, etc. Informal conversations with colleagues who are assigned to teach courses for non-majors suggest the lack of strategic resources for course development and teaching. Filling this gap would be a valuable contribution toward meeting the ABET criteria[21].

Therefore, the following directions for future studies are needed:

1) Summative, including:
    a. Deeper analysis of the information already collected
    b. Verification of whether the results reported here are reproducible in future semesters.
2) Formative, including:
    a. Improvement of the existing EE course for non-EE majors, to enhance student interest, motivation, and confidence
    b. Application of the methods, which have been successful in this course, to other courses for non-majors.

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