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A Pilot Study of a Novel Set of Three Courses for Teaching Electrical System Analysis to Mechanical Engineering Students

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Abstract

For many years in the mechanical engineering curriculum, the topics of electric circuit design, mechatronics and instrumentation have all been taught as separate courses. However, these topics are all fundamentally related through the manipulation of electrical energy to produce some desired result, whether it be to turn on a light, drive an electric motor, or measure the stress in a beam. In an effort to more explicitly demonstrate how these subjects are related, a set of three courses, meant to be taken concurrently, was developed to integrate these topics. Two lecture based courses, one covering mechatronics and one covering instrumentation and experimental design, as well as a laboratory course that put to use the knowledge gained in those lectures, were created and implemented during the fall semester of 2014. The students enrolled in these three courses were junior level (third year) students. The lectures for both courses were taught by one faculty member (i.e. Faculty A), while a second faculty member (i.e. Faculty B) taught the lab course. In the following year, the faculty who taught the lab course (Faculty B) taught one of the lectures while the other taught a lecture and the lab. Close collaboration between the two faculty members ensured that the topics being covered in lecture kept pace with the labs so that students were able to see the theory and then put it directly to use in the laboratory. Two methods of evaluation of course learning outcomes suggested that students were better able to relate topics that were common between courses and had a stronger understanding of all topics. Assessment of the course learning outcomes included the analysis of final exams and midterm quizzes. Additionally, a pilot study of semi-structured interviews with six students from the first cohort has also been performed to determine whether students recognized concepts from this course in a different context, namely the students' senior design projects.

Introduction

Electrical concepts and the basics of electrical engineering and circuit design are a fundamental part of every mechanical engineering (ME) curriculum. Electro-mechanical systems are becoming much more prevalent than they have been in the past and it is imperative that every mechanical engineer can understand and apply basic electrical concepts to the analysis and design of these systems. It is also becoming increasingly important for students to be able to deal with a union of electrical and mechanical systems.

The traditional mechanical engineering program has generally included a course taught by an electrical engineering (EE) department. This course is typically entitled "Introduction to Electric Circuit Design" or "Introduction to Electrical Engineering." The benefits of this course being taught by the EE department are numerous. The students are exposed to a different type of analysis and a different approach to the design of electrical systems. They are also exposed to faculty in other departments that may have different approaches to problem solving. However, when a student attempts to incorporate electrical concepts and systems into a mechanical system, it can be difficult to combine the two analytic techniques.

Another issue occurs if a particular university does not have an electrical engineering department or any EE faculty. Without an EE department to teach the introduction to electrical engineering course, or even the introduction to circuit design course, how are the mechanical engineering students supposed to learn these important concepts? The ME students at St. Martin's University have historically been reliant on ME faculty to teach the traditional Introduction to Circuits course. While the ME faculty are competent in circuit design, they are not electrical engineers by training and so the course loses some of the value of having an EE faculty. As such, the Introduction to Electrical Circuits course was removed from the curriculum and replaced by a novel set of three courses in the ME department at St. Martin's University.[1] This three course sequence included a course in Mechatronics, a course in Instrumentation and Experimental Design, and a laboratory course that would benefit both of the lecture courses. These three courses totaled 7 semester credit hours and were designed to be taken during the fall of the junior (third) year. A full description of the three courses can be found in Ref. 1.

The courses were designed to be taken concurrently for a number of reasons. The ME program at St. Martin's University is a small program that typically offers each required course only one time per academic year. Due to this restriction, the concurrent nature of all three courses did not seem to be an undue burden on the students' scheduling. In the rare case when a student must take them out of sequence, the student generally will take Mechatronics first, as this course contains most of the underlying electrical concepts.

Some of the course learning outcomes and concepts are common to both lecture courses and reinforced by the lab. When students are being exposed to the same concept from different perspectives they tend to internalize the information more effectively. These courses were designed such that electrical concepts in particular were reinforced and introduced through applications in mechatronics and instrumentation and then realized in a laboratory environment. Taking all three concurrently gives students the practice and exposure necessary for full internalization of the concepts. The assessments and interviews that comprise the remaining sections of this paper are a pilot study to determine the effectiveness of this approach.

This paper will discuss the course learning outcomes for both lecture courses and introduce some assessment tools. The results of the application of those tools will be discussed along with a pilot study using interview data. Finally, a proposal for a future line of inquiry will be presented.

Description of Course Learning Outcomes

The set of three courses was developed to achieve desired course learning outcomes that cover a wide range of electrical and mechanical systems concepts. Some of the course learning outcomes were similar in the two lecture courses, while the lab course was meant to combine and apply the knowledge gained in both of the lectures.

The course learning outcomes for the first course, entitled "Instrumentation and Experimental Design" were listed in the course syllabus as follows.

Upon completion of the course, the following course outcomes are desired:

1. students will have a clear and thorough understanding of concepts, principles, and methods of measurement, instrumentation, and experimental design;
2. students will be familiar with the operation and uses of a number of measurement systems, including the following:
    - electrical (e.g. thermistor, strain gage, transducer, displacement indicator, tachometer),
    - fluid mechanic (e.g. pitot tube, flowmeter),
    - optic (e.g. anemometer, velocimeter, IR detectors), and
    - thermoelectric (e.g. thermocouple);
3. students will understand basic signal conditioning, processing, and recording;
4. students will understand instrumentation calibration and response;
5. students will be able to analyze design-stage uncertainty;
6. students will understand signal characteristics, the Fourier transform, and digital signal analysis;
7. students will understand the basics of probability, statistics, uncertainty analysis, regression, and correlation;
8. students will be able to write a technical report; and
9. students will understand and be able to communicate the broader context of the course material.

These course learning outcomes reflect the nature of the course in Instrumentation and Experimental design that is meant to teach those broad subjects. However, the ideas of signal conditioning, processing and recording, as well as signal characteristics, are all derived out of the electrical concepts inventory. These concepts in particular overlap with the course learning outcomes for the course entitled "Mechatronics" which has the following stated course learning outcomes.

Upon completion of the Mechatronics course, the following course outcomes are desired:

1. students will have a clear and thorough understanding of concepts, principles, and methods of modeling mechanical, electrical, and electro-mechanical systems;
2. students will be familiar with the operation and input and output characteristics of the following electrical circuit elements:
    a. resistors,
    b. capacitors,
    c. inductors,
    d. diodes,
    e. transistors, and
    f. operational amplifiers;
3. students will understand the designs of basic circuits;
4. students will be able to model electrical and mechanical systems with a unified modeling technique;
5. students will be able to construct state-space models (including state equations) of electrical, mechanical, and electro-mechanical systems;
6. students will be able to analyze the characteristics of system models;
7. students will be able to solve for first- and second-order linear (time-invariant) system responses;

8. students will be able to solve for general linear (time-invariant) system responses;
9. students will understand the larger contexts of electro-mechanical system dynamics, especially with regard to technology development and society; and
10. students will be able to communicate what they are learning and its broader contexts.

These course learning outcomes are similar in scope to those of a standard "Introduction to Electrical Engineering" course, or another course of that nature. However, this course also includes aspects of the combination of mechanical and electrical systems. This reinforces the electrical concepts by using them in context as soon as they are developed.

The laboratory course uses laboratory exercises to reinforce and apply the material taught in both lecture based courses. The application of this material in a combined manner allows students to see the material in yet another situation and apply the principles and theories learned in the class room.

Method of Assessment of Course Learning Outcomes – Instrumentation and Experimental Design

The course learning outcomes for the first lecture course (I&ED) were assessed using traditional homework assignments and both mid-term and final examinations. Specific questions were developed to determine the extent to which students had learned and retained the knowledge gained in both this course and the related lecture course on Mechatronics. This section will describe the assessment tool to assess the learning outcomes related to three specific topics: RC Filter design, Dynamic system response, and the analysis of Wheatstone bridge circuits. Two of these topics, dynamic system response and RC filter design, were directly covered in the Mechatronics course as well as in the I&ED course. The topic of Wheatstone bridge circuit analysis uses basic electrical knowledge and analysis techniques also learned in Mechatronics, but with an application in instrumentation.

The assessment tool used for assessing learning outcomes is the final examination given at the end of the semester. A total of 34 students were enrolled in the course and participated in the exam. Three separate questions on the exam were used in the assessment and will be detailed here. All of the students were given the same examination, however two versions of the exam were created with only the order of the questions changed to discourage cheating. The exam was scored out of a total of 100 points and the overall average on the exam was 77/100. For reference, the average grade for the entire course was 82%.

The question dealing with RC filter design was worth 5 possible points and students were given partial credit based on the completeness of their answers. The question was stated as follows:

> The signal 10sin(20t) passes through an RC filter with a magnitude ratio of 0.75 and then through an amplifier. What is the gain, G, of the amplifier for the output signal to have an amplitude of 15?

This question was designed to be a quick question that students would be able to solve quickly. The design and placement of an RC filter within a larger system that includes amplifiers was part of the electronic concepts inventory that students should possess as mechanical engineers.

Another question on the exam was designed to test students' ability to analyze the dynamic response of a system to either step or sinusoidal input. This concept overlaps in many different areas of engineering, including electrical, mechanical, chemical, aerospace, and others. The dynamic system response has its roots in mathematical theory but can be applied to various systems that behave as first or second order systems. The question was stated as follows:

> A strain gage is mounted on a cantilevered beam to measure oscillations. The second order system has a natural frequency of 200 Hz and ringing frequency of 150 Hz.
>
> *a)* Determine the damping ratio of the system.
>
> *b)* Determine the magnitude ratio when the system is subjected to a 275 Hz oscillation.
>
> *c)* Determine the phase lag for the 275 Hz oscillation.

This question was given a total of 15 possible points with each part of the question worth 5 total points. Students were given partial credit based on the completeness and correctness of their answers, however, care was taken not to propagate mathematical errors early in the problem to later parts. For example, if a student made a mathematical error in determining the proper damping ratio in part (a) and used the erroneous damping ratio for the calculation of the magnitude ratio if part (b), the student was not penalized twice, as long as they used the proper formula and analysis for part (b).

The final topic of interest to this study was the analysis of the Wheatstone bridge. This topic was covered solely in the I&ED course but relied heavily on basic electrical concepts developed early on in the Mechatronics course. This topic is a good example of students' ability to take electrical concepts developed with applications in Mechatronics and put them to use in a different context. The question was stated as follows:

> Two resistors, R_a and R_b, arranged in parallel, serve as the resistance, R_1, in the leg of a Wheatstone bridge where R_2=R_3=R_4=150 Ohms and the excitation voltage is 5.0 V. If R_a = 750 Ohms, what value of R_b is required to give a bridge output of 1.0 V?

This question was given a total of 15 points. Again, partial credit was given based upon the completeness and correctness of the answers. This question allowed the students to demonstrate knowledge of the analysis of a Wheatstone bridge circuit.

Methods of Assessment of Course Learning Outcomes – Mechatronics

Methods used to assess the Mechatronics course learning outcomes include the identification of key concepts, selection of quiz and final exam questions that may be used to query for understanding of these concepts, and the analysis of the resulting data. Five concepts were selected:

1. RC filters,

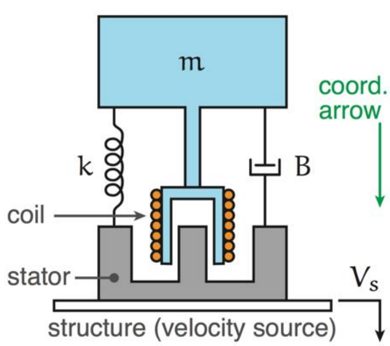
2. frequency response,
3. DC circuit analysis,
4. AC circuit analysis, and
5. electromechanical system analysis.

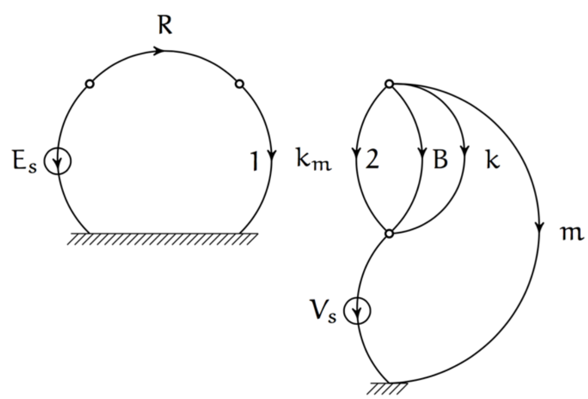
The first two of these explicitly cross-over with the I&ED course, the third includes the Wheatstone bridge concept from the I&ED course, and the last two encompass many of the key course learning outcomes.

The first four concepts were assessed by selecting a collection of quiz questions that pertained to the concept. Eight quiz questions were selected, two of which were three-concept questions and one of which was a two-concept question. Due to the binary nature of the quiz results, which were multiple-choice, an assessment similar to that in the preceding question was impossible. Instead, multiple questions per concept were selected, and the aggregate mean scores were computed. (Note that the scores were computed by weighting each individual problem mean by its number of attempts.)

The fifth concept was assessed by selecting the most integrative and involved question from the final exam. This question is presented below.

> The schematic shows an electromechanical system (an *inertial actuator*) with a *linear motor*, which is a device that converts between electrical and translational mechanical energy. A linear motor has two elemental equations: $e_1 = -k_m v_2$ and $f_2 = k_m i_1$, where we are using e for voltage, v for velocity, f for force, i for current, and k_m for the linear motor constant. The linear graph is drawn [beside] the schematic. Respond to the questions and imperatives below. Use the sign convention from the diagram.





a. Is the linear motor a transformer or gyrator? Why?
b. Draw the normal tree, define the state vector $\boldsymbol{x}$, define the input vector $\boldsymbol{u}$, and find the system order n.
c. Write the elemental, continuity, and compatibility equations.
d. Solve for the state equations in standard form.
e. Let the single output y be the reaction force on the structure $f_R = f_2 + f_B + f_k$. Write the output equation in standard form.

Table 1. Percentage of students scoring at a given percentage for each of three topics. A total of 34 students participated in the exam.

Topic	100-90%	89-80%	79-70%	69-60%	59-0%
RC Filters	53%	9%	0%	24%	15%
Dynamic Response	68%	15%	0%	3%	15%
Wheatstone Bridge	50%	29%	0%	6%	15%

This question asks the student to demonstrate a thorough understanding of electromechanical system analysis. It also provides an opportunity to assess student performance in the same manner as the assessment of the preceding section.

Results for Assessment of Course Learning Outcomes

The three questions asked as part of the I&ED final exam were worth a total of 35 points out of the 100 possible points. Table 1 shows the statistics of the number of students who scored within a certain range on each question. The question on RC Filter design had the lowest average score at 79% while the questions regarding dynamic system response and Wheatstone bridge circuit analysis earned 83% and 85%, respectively.

The data presented in Table 1 shows a rather bimodal distribution of scores on all three topics tested in the I&ED course. The majority of the students displayed a thorough understanding of the topics in question. However, a small minority of students did not fare well on these exam problems. Five of the 34 students performed very poorly and either skipped the question entirely or did not show any mastery of the material. These five students did drop the overall average on each of these questions. If those 5 students are removed from the population, the average scores go up to 87%, 93%, and 91% for RC Filters, Dynamic Response, and Wheatstone Bridge, respectively. These scores show that the students were able to take these electrical concepts that were developed in both I&ED and Mechatronics and apply them to these specific topics.

The Mechatronics learning outcomes assessment results are presented in Tables 2 and 3. Table 2 shows the aggregate mean scores on questions by concept. The first three of these concepts have significant crossover with those of the I&ED course. These scores were among the highest, overall, suggesting that the crossover may have led to a better understanding of these concepts.

The two non-crossover topics, AC circuit analysis and electromechanical analysis, were assessed using questions from different contexts; the former from quiz questions and the latter from a final exam question. Another difference is that AC circuit analysis was itself a crossover concept, albeit without much explicit coverage in I&ED. This may further support the idea that concepts with crossover are better understood. It is notable that electromechanical system analysis was completely absent from the I&ED course, making it the sole concept without any crossover. The distribution of scores on the final exam question used to assess this are presented in Table 3.

Table 2. Aggregate mean scores on selected Mechatronics assignment questions by topic. All questions were selected from quizzes with the exception of the electromechanical analysis question, which was from the final examination.

Topic	Aggregate Mean
RC Filters	91%
Frequency Response	84%
DC Circuit Analysis	89%
AC Circuit Analysis	84%
Electromechanical analysis	66%

Table 3. Score distribution for the selected Mechatronics final examination question. A total of 41 students participated in the exam.

Topic	100-90%	89-80%	79-70%	69-60%	59-50%	49-0%
Electromechanical analysis	29%	12%	7%	12%	10%	29%

The results of the learning outcomes assessment show that students exhibited understanding of selected concepts, while still embedded in the context of the Mechatronics or Instrumentation and Experimental Design courses. However, this result only limitedly addresses one of the main drivers for constructing these courses. The authors developed the courses in hopes that students – despite limited exposure to electrical systems – could apply their constructed knowledge to other mechanical engineering contexts. As a response to this issue, the authors began developing a pilot study examining if and how students applied concepts in the courses to other contexts. One context that served as a mediator for this goal was the students' senior design project.

Methods of Evaluating Students' Application of Concepts in Other Contexts

One of the key outcomes for both courses was for students to recognize concepts in contexts beyond the Mechatronics and Instrumentation and Experimental Design courses. In order to evaluate this outcome, the authors developed an exploratory pilot interview focusing on students' identification and recognition of the application of course concepts into their senior design projects. The pilot interview was qualitative, semi-structured, and open-ended in nature.[2,3] The interview protocol is listed in table 4.

In order to explore students' ability to recognize and identify mechatronics, instrumentation, and experimental design concepts without biasing their answers at the initiation of the interview, the protocol followed a specified format. The first stage of the interview allowed the students to explain their senior design project (i.e. their roles, problems faced, and stage in design). The second stage of the interview engaged students in talk about concepts that were applicable to their senior design without biasing them to focus on concepts only applicable in the Mechatronics and Instrumentation and Evaluation course. The third stage of the interview directly inquired about specific concepts in the developed courses and its application to the students' senior design project. The fourth stage asked to students to talk about other contexts in which they foresee using the concepts. The interviews were not designed to assess students' conceptual understanding of topics covered in the courses, but rather as a means to explore if students recognized concepts in their senior design work, and how the students chose to apply those concepts in that context.

Table 4: Interview Protocol

Stage of Interview	**Main Question**	**Probes/Subsequent Questions**
01 – Providing context for their senior design project	• Tell me a little about your senior design project.	• What's your role in the project? • What are your tasks for the project? • What types of problems are you trying to solve? • What is your current design for your project?
02 – Identifying concepts in their senior design projects	• In regards to your senior design, what "big ideas" or concepts from past classes have you used so far?	• How did you use those "big ideas" in your senior design project? • What are other "big ideas" from past classes that you think you'll be using in your senior design project between now and the end of the semester?
03 – Directed questions about concepts taught in designed courses and its application to senior design projects	• Were there any instances that you used "big ideas" from [Mechatronics/ Instrumentation and Experimental Design] class(es)?	• What "big ideas" did you use? • How did you use these "big ideas"? • Why did you use them in the manner that you used them?
04 – Identifying contexts beyond senior design to apply concepts	• With the concepts you learned in the [Mechatronics/Instrumentation and Experimental Design] class(es), do you think you'll use them in other contexts outside of senior design?	• What are those other contexts? • What concepts do you think will be useful?

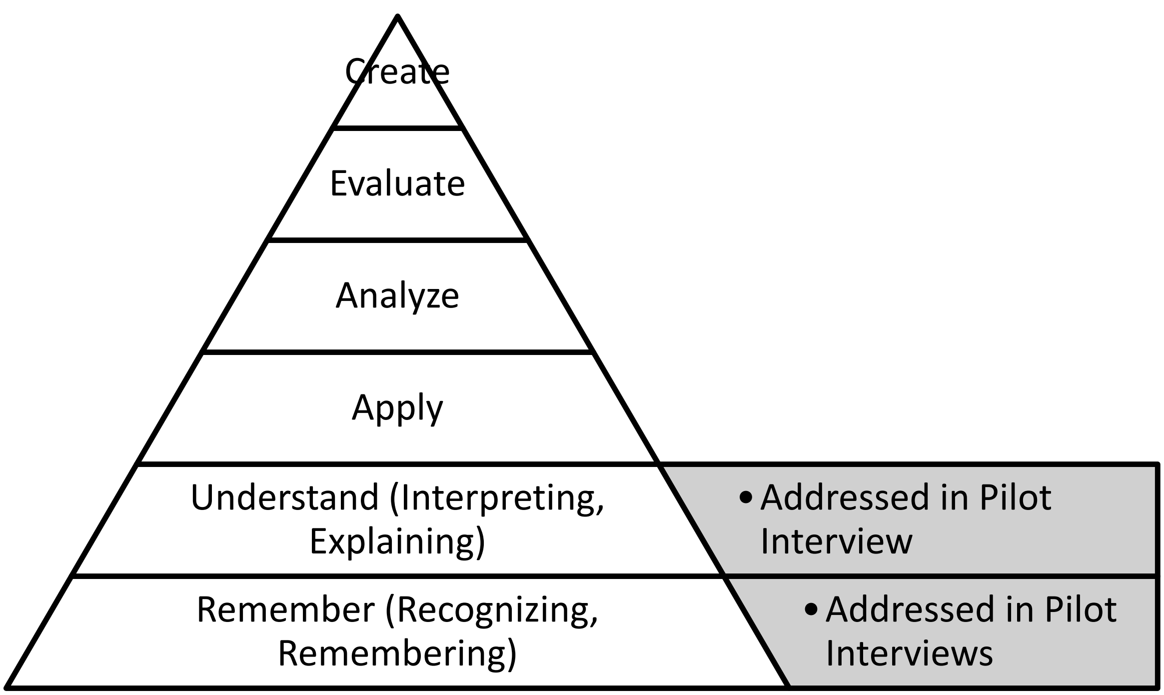
All of the students in the first cohort were provided the opportunity to participate in the pilot interviews. One of the authors sent an email to all of the students in the first cohort asking for volunteers. An incentive of extra credit in one of his courses was provided for participants. Six students responded and participated in the pilot interviews. Due to the self-selected nature of the sampling, as well as the qualitative nature of the interview, the analysis of the data from the interview should not be viewed as statistically representative of populations of students. Instead, the interviews are meant to provide deeper insight into students' perspective on the application of concepts between contexts and how those students applied meaning to the concepts they were exposed to in the courses. Indeed, this form of interview is founded on the interpretivist framework, wherein meaning is constructed based on the ways individuals engage and interpret the world.[4,5]

Due to time constraints, the interviews occurred prior to the students' completion of their senior design projects. The senior design course is a two-semester sequence. This meant that students were only halfway through their actual design at the time of the interview, which occurred in the beginning of the spring semester. The interviews, which were conducted in a single day, lasted between 5 to 15 minutes per student. All of the interviews were audio-recorded with permission from the participants. Only one of the authors, who was not an instructor in either of the developed courses, conducted all of the interviews. The interviews were transcribed and then uploaded into Atlas.ti[6], a qualitative analysis software. Prior to analyzing the interview data, Faculty A developed a list of 91 codes identifying relevant concepts in the courses. This list served as the code categories for the interview data. If the student mentioned any of the words on the list, it was coded for that specific concept.

Results of Evaluation of Students' Application in Context of Capstone Project

The main goal of these pilot interviews was to initiate examination of students' understanding of concepts across contexts. Undoubtedly, "understanding" has variable degrees of depth. In order to better categorize the "understanding" examined in this study, the authors utilized a model of Bloom's Taxonomy[7], which served as a guide for the process herein. Figure 1 represents the level of understanding examined in this study. Note that only two of the lower levels (remembering and understanding) were examined in this study. The authors only sought data that reflected students' ability to recognize concepts and explain the meaning of the concepts in relation to their senior design projects. Future iterations of this study will examine deeper levels of understanding inclusive of students' observable abilities in applying and analyzing concepts in various contexts.

Figure 1. Bloom's Taxonomy and Application to this Study



Analysis of the data revealed that students participating in the pilot interviews identified relevance (and in some cases, irrelevance) of course concepts in their senior design projects. The students interviewed for this study represented four of the senior design project teams. The senior projects included the design of a rocket burner that generates power, a drill/injector device that allows the injection of hormones into living trees, wind turbine embedded in an electric vehicle, and the redesign of a temperature gauge for chemical processes. Table 5 summarizes which students identified relevance of content taught in the designed courses to their senior design project, along with excerpts from their interviews.

Table 5: Perceived relevance of the Mechatronics, and Instrumentation and Experimental Design in senior design projects

Student ID	Senior Design Project	Relevance of Concepts to Senior Design identified by student (Y or N)	Interview Excerpt
01	Rocket burner	Y	Yeah- well, yeah because a lot of- I've been working- we haven't incorporated that but that- all of the instruments that we use can put those numbers for like error and stuff in there for our test so we have better numbers- or more accurate numbers. And that's like what we learned about in that class, right? To have- to show how much error there is.
02	Drill/ Injector	N	Not specifically. We didn't use any electronics so there's no real control. We'd have the drill, but again it's something that we're not changing so we're not going to consider any of the controls for the drill. There's no need to. All we have is a drill bit extension, which doesn't change the torque on the drill at all cause it's made to just be a really long drill bit.
03	Wind Turbine	Y	[pause] Kind of. So, I'm gonna- so we didn't actually get to the part- we're not doing the part of the actual power generation. We're just building the wind- the windmill, I guess, itself. I'm going to continue this later. So, once I start doing the power. Then my mechatronics systems classes will come into play. And, we don't really have classes that deal with pow- or with wind turbines or alternate energy really. Something like that would have helped a lot. Fluids helped a little bit, because we're dealing with wind. But, yeah, I think later it'll be mechatronics and systems is going to be playing a big role.

04	Wind Turbine	Y	Yeah. I think fluids was a good one. Machine design was a really big one. Manufacturing Processes was a really big one too. [pause]. I think those were the three biggest ones. And, I think if we could actually test this stuff, systems and mechatronics would be good, because you can actually design a system, model it, test it, and put it together to see if we- you know, how it would work.
05	Wind Turbine	Y	Okay, yeah, so a little bit of everything. Not so much any thermo, but a lot of fluids because air is a fluid, and we're using that. A lot of mechatronics, I want to say, we've been using some of that, because that's what we learned about you know transferring energy from electrical to mechanical or rotational. What else did we use? System dynamics, that goes along with mechatronics.
06	Temperature Gauge	Y	Oh, okay. [pause] Not yet. I'll say that, not yet…Because we have to find a way to take the wavelengths and transmit it into software. So there'll be electric components that'll have to- that can get worked in there. That's where I think mechatronics will come into play.

Of the six students interviewed, five acknowledged the relevance of the courses to their senior design project. Students' talk reflected a wide range of perceived relevance of concepts taught in the course to their specific senior designs. For example, Student 04 identified specific applications of the concept to his group's design:

> "It'll be like hooking the circuits up and how much energy we can actually take off, and the transfer of the energy. You know, the transfer function- figuring out how much, you know, how much [energy] you collected, and set it up as a circuit." (Student 04 Excerpt)

In comparison, Student 06 only briefly noted the presence of electrical components as the link between his group's senior design and the courses:

> "So there'll be electric components that'll have to- that can get worked in there. That's where I think mechatronics will come into play." (Student 06 Excerpt)

In general, students were able to identify at least one concept taught in either the Mechatronics or Instrumental and Experimental Design relevant to their senior design project. This indicates, at least at a superficial level, that students recognized concepts taught in the courses across different contexts. This addresses a minimum expectation for the course outcomes.

Students' talk also reflected a wide range of concepts applicable to their senior design project and other contexts. Students tended to speak about two major concepts taught in the courses: 1) transformation of electrical energy to mechanical energy (and vice versa), and 2) experimental design. Table 6 summarizes the emergence of specific concept codes in students' talk.

Table 6. Emergence of concept codes in students' interviews

Stage of Interview / Student ID	01	02	03	04	05	06
01					Batteries; Current	
02			Electrical; Mechanical; Electrical transformers; Motors	Experimental planning	Electrical Transformer; Electrical; Mechanical	
03	Errors; standard deviation	General mechatronic	Electrical; Mechanical; Electrical transformers; Motors	AC Circuit Analysis; DC circuit analysis; Experiments	Current; Electrical Transformer; Voltage; Mechanical; Electrical; Motors; Signals; AC circuit analysis; DC circuit analysis; Batteries; Motors; Experiments	Electrical;
04				Electrical transformers; Mechanical		General Mechatronics

Manifestations of talk reflecting understanding of application of the listed concepts ranged greatly. For example, Student 01 identified concepts taught in the courses, like standard deviation and error, but when prompted to expand on how he would use these concepts, he was unable to do so:

> "Oh, like the temperature and the voltage and the pressure and the velocity- all that can be [pause]… Right. All those readings can be- I can't remember exactly how- But yeah, they're just- Like standard deviation and then percent error and then- I can't remember exactly all the steps how to do it." (Student 01 Excerpt)

On the other side of the spectrum, Student 05 expanded on the application of mechatronics concepts into "real-world" contexts related to his senior design project:

> “Oh, yes. So, basically, mechatronics just deals with electricity and, you know, what’s it do and how does it get from places. So, you know, you have a wire, then you have a current, which is [like] just electrons- yeah, electrons going through the current. And they do certain- they create a magnetic field, which we could use. So, right now there’s a thing called a transformer. Not like the ones you see outside- that transformer of electricity, but- What a transformer does is it just [so] much electrons- and it’s kind of like a generator. And it gets hooked up, and what it does is it transfers your electrical energy into mechanical energy. And through that process, that’s how you’re able to get like motors, which transfers to gears, and it transfers to the shafts, and that can rotate stuff like wheels, you know. So you’re [mumble] [in] your car has a motor inside, and then you push the button on your remote control sending a signal down to the motor telling it to send a current to here. It’s going to spin, and boom your wheels are going to spin.” (Student 05 Excerpt)

This wide range of responses may not be completely reflective of students’ deep, conceptual understanding of the concepts. Indeed, getting conceptual understanding data was not the goal of the pilot interviews. However, this points to a possible iteration of future inquiries regarding this course. Beyond examining a listing concepts mentioned by students, which only addresses remembering in Bloom’s Taxonomy[7], a future iteration of the interviews may explore deeper understanding by engaging students in more focused interviews about specific concepts addressed in the courses.

Conclusions

Evaluation of students’ responses to exam and quiz questions indicates that students exhibited understanding of electrical concepts while in the courses. The pilot study of interviews revealed some insights, namely that students seem to recognize and identify relevance of concepts in the context of senior design projects. A next step in this research is to further examine students’ deep, conceptual understanding and their application of knowledge to mechanical engineering designs and problems. A future iteration of this study will utilize clinical interviews paired with task activities to examine students’ conceptual understanding and process of thought. This method of inquiry has shown to be an effective means of identifying structures in problem solving and patterns of conceptual understanding.[8-9] Further, this future iteration will provide greater detail regarding the effectiveness of the course in developing students’ understanding of electrical concepts, as well as identify the structure of student thinking when faced with solving contextualized problems.

We can say that our students have developed all of the skills and demonstrated that they have, in fact, achieved all of the course learning outcomes. They have grasped all of the electrical concepts without having had an electrical engineering course or circuit analysis course.

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