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WORK IN PROGRESS: Authentic disciplinary context in circuits-for-nonmajors

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Brian Faulkner's interests include teaching of modeling, engineering mathematics, textbook design, and engineering epistemology. He is also interested in best practices for service courses for nonmajors, particularly circuits-for-nonmajors, and the impact of authenticity of assessment tasks.

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Abstract

WORK IN PROGRESS PAPER: Many non-electrical engineering students take an electric circuits course. These courses present challenges for the instructor; students may arrive with little motivation to engage with content outside their chosen major. Previous research has already examined motivational issues in this and other service courses, such physics-for-life-scientists, mathematics-for-engineers, and chemistry-for-nonscientists. The author taught circuits-for-nonmajors following a strictly applied approach. All circuits analyzed in class or on homework were circuits for disciplinarily authentic devices, such as household wiring, electrostatic precipitators, resistance thermometers, roadway lighting, or hydrogen fuel cells. This paper shares two examples of the applied circuits homework exercises, the task design philosophy and student responses to feedback surveys.

1 Introduction and Background

Many engineering students who are not electrical engineers will take a course in electric circuits during their undergraduate degree. For mechanical engineering students, this is often a prerequisite for mechatronics or robotics courses, for biomedical engineers it may be followed by study in medical instrumentation[1] and it is the final exposure to electrical phenomena in college for most civil engineers. Many of these students believe their circuits course is irrelevant to their chosen path of study, that they need only concern themselves with the world of pounds and feet, and never the world of volts and amps.

Motivation to engage in this course can be low[2,1] since it does not align with students' chosen major of study. Some have previously studied the desires of the client disciplines in more detail[1]. Circuits is not unique in this aspect, nonmajors are often unmotivated to engage[3]. Life science majors are often disengaged in introductory physics classes[4,5,6,7], engineering students can struggle to find their calculus courses relevant to engineering[8,9], and non-science majors, both poets and engineers, may perceive of general freshman chemistry as useless, abstract, and irrelevant[10,11]. One strategy that can be effective is providing authentic disciplinary context to scaffold the theoretical content[12]. In the previous literature, favorable results follow the inclusion of authentic, disciplinarily realistic tasks. Nonmajor students are more motivated to engage with the content when shown plenty of evidence that this seemingly unrelated course is relevant to their disciplinary interests and career goals.

In calculus-for-engineers, this approach involves presenting situations in engineering where the mathematics being learned describes an engineering system, such as derivatives in the context of projectile motion, or integrals in the context of fluid pressure on dams[8,9]. One textbook[13] presents introductory precalculus and calculus entirely with engineering examples, every example problem and homework problem has genuine engineering context such as strain gauges, resonant circuits, or rocketry.

This strategy has also been followed in "introductory physics for life sciences" (IPLS)[14,5,6]. The highly abstract nature of physics and memorization-favoring mindset of life science students do not match well, and biology students are sensitive to biologically inauthentic situations in class[14]. This group reformed their IPLS course to include many authentic examples of the relevance of physics to future biologists, ecologists, physicians, and nurses. The construction of homework tasks stress how biologists can use physics thinking to solve biological problems.

A similar strategy has been pursued in introductory general chemistry for non-scientific majors[10]. One course uses environmental chemistry as a context and setting to motivate the learning of traditional topics in freshman chemistry. The environmental issues are not explored in full depth, but form a motivation and background for the theoretical study in general chemistry. Another course[11] chose space science topics including rocketry, fuel, and solar energy as contexts to motivate engineering students to engage with general chemistry topics like the enthalpy of reactions. Care must be taken to present content in such a way that the context enhances, rather than distracts from, the core theoretical knowledge to be taught.

1.1 Previous Literature on Circuits-for-nonmajors

"Traditionally, the content of the EE service course is a cut-and-paste combination of some of the content of courses offered to EE students."[1]. Topics not related to nonmajors intended area of study are swiftly forgotten[1]. Often, the course contains much difficult mathematical calculation and little in the way of practical examples to motivate theoretical study[15,2,16,17]. The specific circuit arrangements solved may be random and arbitrary, rather than genuine diagrams of real machines[2]. These previous efforts have focused on the laboratory portion of the course to increase student motivation, using micro-controllers, instrumentation, and interdisciplinary projects to add authentic context. Less research has focused on homework problems that the students solve, and the exam questions they complete for the majority of their grades. Circuits textbooks such as Nilsson[18] or Hambley[19] contain just one applied task per chapter, with the rest being abstract tasks.

As a first-year faculty member, I was assigned the circuits-for-nonmajors course, which primarily serves civil engineers and chemical engineers and has no laboratory component. The course was reworked to cover the usual topics, but in the context of genuine civil and chemical engineering devices. Emissions by power plants were the context for KVL problems, induction loop traffic detectors illustrated phasor analysis, and wastewater impellers were used to study AC power.

2 Task Design

Designing applied tasks for nonmajors is difficult. The students have less buy-in to the content, and may have weaker mathematics skills than more mathematically-inclined electrical engineering students[20]. I constructed tasks from the raw material of government design handbooks, hobbyist tutorials, datasheets, and technical application notes. The intent was to have all aspects of the tasks demonstrate the utility of circuit theory to students' disciplinary ambitions. Tasks explore a deliberately wide variety of machines, from high-power pumps to low-power sensors.

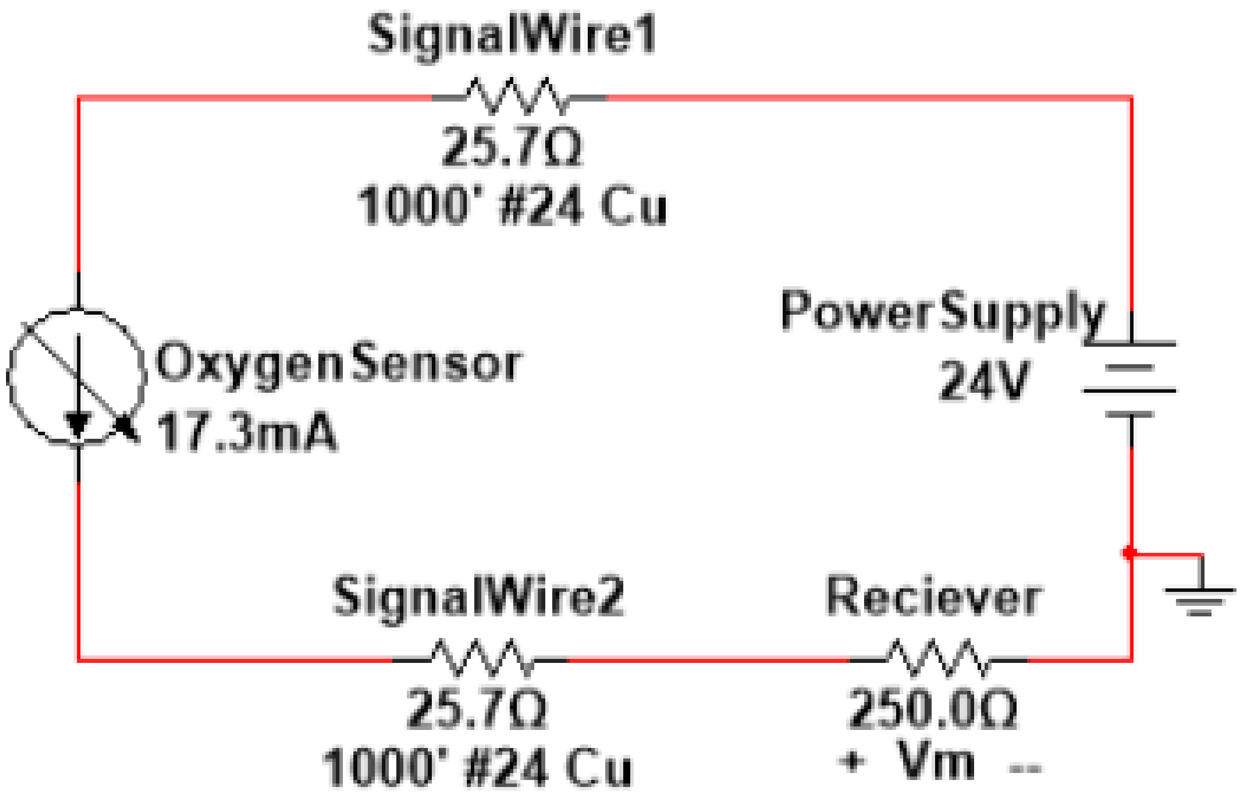
Meredith et. al.[5] provides a framework for constructing and evaluating application tasks. Examples of how these principles were applied in circuits accompany them.

- Application tasks should balance tractability with applicability. Use the simplest rather than the most accurate model of the system. Side-by-side comparison of nearly-identical systems can be very effective.
- Application tasks should connect fundamentals to students existing disciplinary knowledge. Applied asks remind students of non-electrical knowledge from first-year classes such as calorimetry and torque.
- Application tasks should incorporate overarching concepts. My overarching concepts included conversion of electrical energy to other kinds of energy, units, orders of magnitude, and machine-function reasoning.
- Application tasks should give sufficient but not irrelevant context and be factually correct. Failure to be factually correct will damage credibility with students. Excessive irrelevant context confuses and frustrates students; two to four sentences works well. Factual correctness includes having plausible component values and genuine objectives to solve for.
- Application tasks should relate to other problems with the same key idea. Reactive loading of antennas and power factor correction of motors both have the key idea "the positive imaginary ohms cancel out the negative imaginary ohms".
- Application tasks should integrate concepts from other realms (geometric, force, energy) while avoiding cognitive overload. Be very stingy with your complexity budget. Additional realms such as reading graphs, conversion of energy, or complex solution strategies can overwhelm students cognitive capacity. Limit each problem to a single additional realm.

3 Example Tasks

3.1 Application Task (Chemical Engineering)

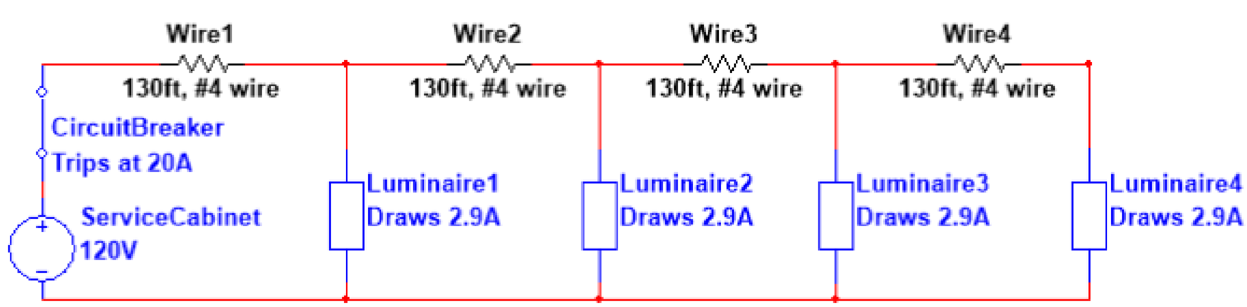
The concentration of oxygen in the industrial environments must be monitored to prevent danger to workers. At normal oxygen levels (20.8% oxygen), the sensor sends a signal of 17.3 milliamps. This small "loop powered" transmitter does not have an internal battery, the same long wires wires that carry the signal to the control computer's receiver also carry the power to the sensor's electronics.



- The oxygen sensor requires at least a 15V voltage drop across it to power its electronics reliably and work. Show that the sensor will work when oxygen levels are normal.
- What power does the sensor provide/consume when oxygen levels are normal?

This Kirchhoff's voltage law problem provides a meaningful example of current sources absorbing power, and illustrates that current sources only behave like current sources under specified conditions. The context of the problem hints to the student that the sensor should be absorbing power.

3.2 Application task (Civil Engineering)



The circuit above is a (simplified) circuit for the lighting in a downtown area. The MN DOT recommends that downtown street lamps (high pressure sodium luminaires) be placed 130 feet apart, and we need to power four luminaires for this piece of street. We connect them with four-gauge copper wire, which has a resistance per unit length of 0.25 milliohms per foot. The luminaires each draw 2.9 amps of current when operating properly. **SODIUM LUMINAIRES DO NOT OBEY OHM'S LAW**.

- The circuit breaker in the service cabinet will trip at 20 Amps. Show that this setup is safe and will not trip the circuit breaker.
- MN DOT requires that the voltage across the furthest luminaire (Luminaire 4) be at least 97% the voltage of the service cabinet. Show that the system is up to code.
- What is the efficiency of the whole system? (Only power delivered to the lamps is useful work.)

This task references the Minnesota department of transportation, a major working body of primarily civil engineers. It focuses on the overarching concept of identifying if a machine works, and does so entirely through Kirchoff's Current Law and Kirchoff's Voltage Law.

4 Survey Response

I surveyed the students anonymously about how the applied homework problems affected their experience of the course. A formal qualitative thematic analysis was not done, but some representative responses are included here. Future work with larger sample sizes and careful controls could explore this more rigorously. This work is only a starting point.

Survey question: "In designing the problems for this course, I have attempted to make the setting and story of each problem context relevant to your majors. How did this impact your motivation and learning in the course? Was there a problem in the course that was the most interesting to you, or felt the most relevant? How could the content have been made more relevant to your interests?"

Applications increase motivation and ease learning

" I sincerely enjoyed learning about the applications and how you modeled them with circuits so that you could analyze them with circuit theory. That gave me a framework to problem solving that I previously did not have before, and I will take that with me for the rest of my life. I especially enjoyed how you broke down physical systems (i.e. not straight wires, caps, resistors, etc.) into their electrical "equivalents", e.g. the cell membrane being both capacitive and resistive."

Many students commented that that applications helped them learn and were more interesting than traditional abstract exercises. However, many students also commented that it didn't do much for them. Students of both majors wanted a greater fraction of the problems to be from their specific major. Students idetify very strongly with their major, which makes presenting to an audience with multiple majors more difficult.

Applications feel less arbitrary

"They all have a point and a topic outside if [sic] do this because I said so" "It was definitely interesting to see that all of the problems we worked on had their own unique stories and

applications. It made the work more bearable because at least I was learning something new while I was doing the work"

Homework is like running laps and doing pushups. It is not fun. The applied tasks can strengthen a student's belief that what they are doing has some eventual value.

Applications increased cognitive load

"I feel like people were confused by the problems because they're not use[sic] to having to pull information from a problem but in the real world, the question isn't always going to be written out in plain English so I feel like the added information is necessary and useful in context of the problem." "As a CHE, I loved the heat transfer part and found it useful. But, I was confused by other aspects because I had no idea what civils were doing and then the ECE on top of it made it impossible."

Application tasks have more to track than abstract tasks. The students had very little practice with word problems in their previous education. Note that sifting through irrelevant or incomplete information are preliminary skills to develop critical thinking[21]. In my experience, it takes the students at least a few weeks to acclimate to solving applied tasks.

Concepts were lost in the context

"I felt as if the electrical engineering concepts were lost by the setting and story. I was disappointed that the problems were incorrect and it made my learning less meaningful." "I enjoyed that the problems were geared towards our disciplines, but I also didn't feel like we were learning the material well enough in class to actually solve problems that were not just straight circuit questions."

Some students did not like the approach, or felt lost. Designing authentic tasks outside ones expertise opens the instructor up to criticism if they get something factually wrong. This class had several final-term seniors taking required sophomore-level circuit theory at the last possible moment. Such students have already taken advanced thermodynamics, so elementary calorimetry models strike them as oversimplified and wrong.

5 Discussion and Conclusions

Writing these problems takes more time than simply drawing a random circuit. It may feel unsustainable to write such problems. Fortunately, many real applied circuits can spawn multiple independent questions. Limiting behavior, maximum ratings, power, efficiency, or another parameter of interest can all be explored in a single circuit. A single circuit can be recycled into several independent problems that ask different questions, stretching the output of one's research. And unlike many forms of teaching innovation, homework problems are easily shared between instructors without dramatic alterations to teaching style or course structure. After all, "Tasks are likely to be the level at which widespread dissemination of curricula is ultimately realized."[22]

Previous research in other domains has identified learning gains from contextual problem solving, but research into this strategy in introductory circuits is limited. Future, more formal research could compare nonmajor students in the traditional, abstract circuit approach to an applied approach. Variables to examine could be effective (perceived relevance of the course, self-reported motivation to participate), performance (average grades, DFW rates, or percent-homework-turned-in), or learning (probability of remembering in one year, knowledge transfer to instrumentation courses). Such studies could provide firm evidence to determine if the applied approach in circuits is a broadly beneficial practice or only a stylistic preference of this particular instructor.

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