GIFTS: Templating Circuit Sub-Systems to Improve Outcomes in a First-Year Circuit Design Project

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Introduction and Learning Objectives

This GIFTS paper describes a circuit sub-system templating approach to improve outcomes in a 1st-year multidisciplinary project-based course at the University of Melbourne. Our students have no declared major during their first year and are often seeking experiences to guide their pathway forward. The course, *ENGR10006 Engineering Modelling and Design (EMD),* is not required but is strongly suggested for students considering engineering. Utilizing project-based learning, a widely acclaimed method for preparing students for the practical demands of the engineering field [1], this course aims to develop students' understanding of the modelling and design processes by guiding them through the life cycle of a real-world engineering project using a blend of lectures and integrated hands-on workshop sessions. Working in teams of three, students choose one of three possible projects at the start of semester. This paper considers the interdisciplinary "speaker project", consisting of following design and implementation aspects:

- Mechanical Engineering: 3D CAD along with laser cutting and/or 3D printing to design and construct a speaker driver and enclosure.
- Electrical Engineering (see Figure 1): Circuit design and implementation for a simple audio equalizer, crossover unit, and filtering out very low frequencies (< 150 Hz) that the constructed driver cannot handle. In addition, students wound their speaker coil and tested audio quality using a measurement microphone and software.

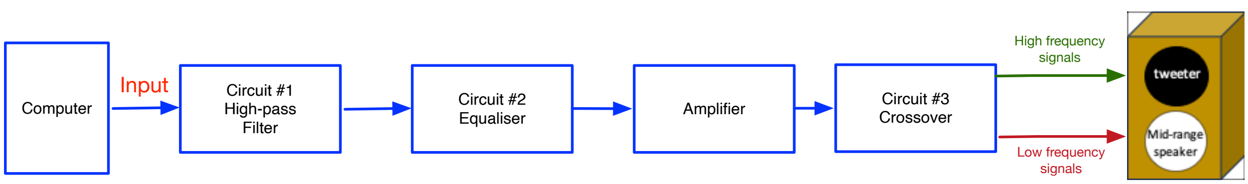

Figure 1: Block diagram of the speaker project. Students designed and constructed Circuits #1, #2, and #3. The amplifier used was an off-the-shelf component.

The only prerequisite for *EMD* is standard high school mathematics (pre-calculus), and student backgrounds can range from little or no physics to those having done some study of mechanics and/or electricity and magnetism. Our semesters have just 12 teaching weeks, and due to start of semester logistics, students only have 10 weeks (9 weeks + 1 break week) for their project work before the final demonstration in Week 12.

This paper focuses on the electrical circuit component of the speaker project, which runs for 5 teaching weeks plus a break week. Due to the varied student backgrounds, in-depth theory could not be taught, and alternative approaches that abstract away some details were instead employed. For example, only very basic circuit theory concepts (KVL, KCL, voltage division) were taught, while more advanced concepts, such as active and passive filters and op amps, were taught with a "functional depth". Students were guided through a systems-based approach, whereby filters and summing amplifiers are viewed as basic sub-system blocks that can be designed and interconnected provided loading effects are properly minimized using a buffer amplifier.

The project's intended learning objectives from the electrical engineering side were as follows:

- (ILO1) Understand the physical principle of electrical-to-mechanical energy conversion (Faraday's Law) that results in speaker cone movement to generate acoustic waves.
- (ILO2) Demonstrate an understanding of frequency response and the ability to design electrical filters for a given criterion.
- (ILO3) Show the ability to implement, test, and debug breadboarded electrical circuits.
- (ILO4) Develop a modular, systems-engineering mindset and learn to do functional sub-system testing to verify correct functionality or identify design or implementation errors.

Motivation

Electrical circuits can be a challenging component in multidisciplinary 1st-year projects due to the confluence of having to understand the underlying mathematics and physics, being introduced to new and abstract concepts, and the construction and debugging issues associated with breadboarding [2], [3]. Simple circuits with a few components are more manageable for students but are not particularly novel or inspiring in building circuit skills and understanding. A primary example of this is the direct connection of actuators and sensors with an Arduino or similar, such as the popular Sparkfun inventor kits along with their guidebook [4] that has illustrated breadboard diagrams showing students exactly where to connect wires and terminals.

More complex circuits with several interconnected sub-systems can embody meaningful applications but are problematic due to their complexity. One relatively safe approach to circumvent much of these issues, while maintaining complexity, is to provide students with a breadboard image of the full circuit to copy, then have them select certain component values.

On the other extreme is the high-risk, (potentially) high-reward approach where students freely breadboard from schematic diagrams with component values they determine to meet desired design goals. Such a 'free-form' approach was used in the first offering of the speaker project in 2022. In a span of 5 weeks, students had to digest some basic theory, design components and select circuit element values, spatially convert a schematic to a breadboard, and test and potentially debug (loose connections, improper/incorrect circuit topologies, incorrect device values, etc.). The most basic working design contained an appreciable number of components: 8 two-terminal passive components (resistors and capacitors), 2 three-terminal components (trimpots), 4 eight-pin 741 op-amp ICs, and many jumper wires.

The unfortunate result of the 'free-form' approach was students focused significant amounts of time on debugging poorly constructed, non-working circuits, which detracted from ILO2 and ILO4 and limited opportunities to observe the phenomena that the theory was describing. Due to the nature of circuit building essentially being a one-person process and students having different ways of spatially mapping schematics to a breadboard, debugging in a team context was difficult. Staff were consequently overwhelmed with debugging help requests, which were time-consuming due to wildly varying implementations.

Methodology and Implementation

In the 2023 offering of the speaker project, to achieve a compromise between the 'breadboard-copy' and 'free-form' approaches, we decided to adopt a somewhat hybrid approach. Students were first instructed to freely breadboard and test simple circuits, such as first-order passive filters. We then provided them with 'black box' templates for larger sub-systems, such as active filters, where they copied their own 'free-form' circuits inside the boxes to make implementation and debugging easier and require less staff assistance. An example of this approach for the audio equalizer (Circuit #2) is shown below in Figure 2, where the `HPF(C2)' and `LPF(C2)' boxes refer to the passive low-pass and high-pass filters, respectively, for Circuit #2 (C2) that students wire themselves just as they did in the first circuits workshop in Week 7. As can be seen below, much of the wiring given to students involves connections to/from the 741 op-amp ICs, which is where most of the wiring problems in the 2022 project offering occurred.

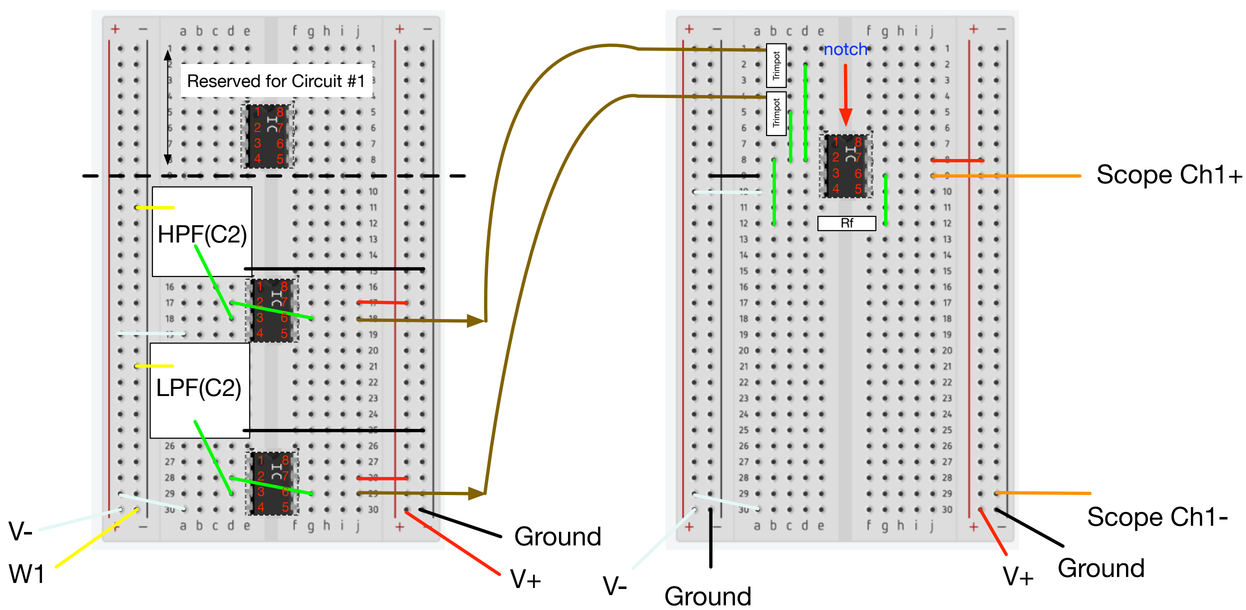

Figure 2: Example of the templated sub-system circuit construction approach for the audio equalizer, where students are responsible for simpler wiring (passive low-pass and high-pass filters in the white boxes HPF(C2) and LPF(C2)) and are given the specific wiring for the larger system to significantly reduce debugging time.

This method also helped students better understand the sub-system approach of tackling a larger design project while reducing concerns about breadboard implementation [5]. The critical concepts of modular design and functional sub-systems were a major point of emphasis, more so in 2023 than in 2022.

Results and Outcomes

We will use the equalizer (circuit #2) to indicate the effectiveness of ILO3 (circuit building/testing) as it is the most complex of the three circuits that students designed and built.

There were 52 groups in the initial running of the speaker project in 2022, of which 34.6% (18 groups) had physically working equalizers with 9 using an active summer configuration and the other 9 using a simpler, less desirable passive summer setup. This result was disappointing, and it was clear that there was too much pressure in having a working circuit (thus satisfying the minimum to meet ILO3), thereby detracting from the other ILOs.

The sub-system template approach used in 2023 resulted in 66.7% (30 of 45 groups) having working equalizers to specifications. Observations of the final project demonstrations indicated that more students met or exceeded the project's minimum objectives than the previous year. Discussions with groups during the project assessment highlighted the ease with which students within the group could identify the various sub-systems comprising the project, in stark contrast with the year before.

Teaching staff reported a significant decrease in time helping students debug their circuits compared to the previous year. With an average of 13 groups in each section in 2022, three teaching staff were needed most of the time for debugging help, so students could complete the tasks for the week. There were 15 groups per section in 2023, and for most circuit-based workshops, only two teaching staff were required with the templated sub-system revision.

Discussion and Conclusion

Complex circuits with interconnected sub-systems can be incorporated into 1st-year subjects with appropriate guidance so that breadboarding problems do not dominate the student experience and negatively affect other intended learning outcomes. Like with any engineering system, tradeoffs were considered after evaluating the project outcomes in the first course offering. The templating sub-system approach proved to be a good compromise between the 'free-form' and 'breadboard-copy' extremes as students were able to achieve better outcomes in ILO2 and ILO4 due to less time and stress debugging circuits. Students still achieved an important sense of accomplishment while developing some circuit building skills as parts of the overall circuit were still free-form. Further breadboarding skills could be developed in electrical engineering courses in subsequent semesters for students who choose to do so.

References

[1] J. E. Mills and D. F. Treagust, "Engineering education—Is problem-based or project-based learning the answer," Australasian journal of engineering education, vol. 3, no. 2, pp. 2-16, 2003.

[2] M. Quezada-Espinoza, A. Dominguez, and G. Zavala. "How Difficult are Simple Electrical Circuit Conceptions? New Findings." European Journal of Educational Research 12.3 (2023).

[3] P.V. Engelhardt, R.J. Beichner; Students' understanding of direct current resistive electrical circuits. Am. J. Phys. 1 January 2004; 72 (1): 98–115.

[4] Sparkfun Inventor's Kit (SIK) Guide: http//sparkfun.com/SIKguide (accessed Feb 8, 2024).

[5] R. Jain, K. Sheppard, E. McGrath, and B. Gallois (2009, June), "Promoting Systems Thinking In Engineering And Preengineering Students" Paper presented at 2009 Annual Conference & Exposition, Austin, Texas.