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Board 25: Work in Progress: Teaching Fundamental Design Principles through Integration of Knowledge and Curriculum Design

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Introduction

Curriculum integration is "*a way of thinking about what schools are for, about the sources of curriculum, and about the uses of knowledge*" [1]. Curriculum integration requires, and should be based on, deep thinking and understanding of the problem [2,3]. In the current system of education, the problem is not about the discipline of knowledge but with the approach and the representation of that knowledge in a way that satisfies a broad population of customers. Are students able to implement and apply the knowledge they learn in school to solve real-life problems? Are they able to make the connection between knowledge and curriculum in an organic way?

In 2019, faculty in the Biology and Biomedical Engineering Department at Rose-Hulman Institute of Technology (RHIT) collaborated to find answers to some of the aforementioned questions and to improve the outcomes of the biomedical engineering program. The main outcome was implementing an extensive curricular revision that was designed to scaffold and integrate topics between courses. By threading topics between (and within) academic terms, faculty can reinforce fundamental concepts and minimize the compartmentalization that challenges many students as they progress through an engineering curriculum [4].

This paper focuses on the impact of scaffolding and integration of topics between two courses that biomedical engineering students take in their sophomore year. These courses are "Design Methodologies" (BE218) and "Circuits, Signals and Measurements" (BE211). In "Design Methodologies", students build hands-on design skills following the Food and Drug Administration's (FDA) design controls process. They design a stand-alone Electrocardiogram (ECG) device on a Printed Circuit Board (PCB). In "Circuits, Signals, and Measurements" students are introduced to physiological signals, amplification principles, filter design, the importance of patient protection, and other instrumentation fundamentals. They implement their circuit designs on breadboards, record signals, and analyze their ECG signals. Designing the ECG circuit on a PCB to meet certain customer requirements is outside the scope of the "Circuits, Signals and Measurements" class.

During the 2021-2022 academic year, the course instructors of the "Design Methodologies" course used the biopotential amplifier lab from the "Circuits, Signals, and Measurements" course to help students connect how their prototyped biopotential amplifiers could be further developed into a more polished finished product. This project was an ideal selection for the "Design Methodologies" course because it reinforced all three-course learning objectives (1- identifying and analyzing product design and development processes, 2- developing the concepts and tools necessary for product design, development, and evaluation in engineering, and 3- designing a product to address unique customer needs) and integrated technical knowledge that students were learning. While "Circuits, Signals, and Measurements" focused on building the biopotential amplifier from a circuit's perspective, the PCB project in aimed at connecting students' learning experience by asking them to manufacture a stand-alone biopotential amplifier device that would meet certain engineering requirements and customer needs (**Appendix A**).

This work-in-progress briefly presents the project requirements, assessment, and organization, highlights some preliminary survey results, and summarizes some important “lessons learned”. The PCB project is not an improvement over prior methods.

Project Requirements & Assessment

Project-based learning (PBL) is a hands-on student-centered experience that allows students to engage in obtaining deeper knowledge and demonstrate their knowledge by creating a product [5]. The PCB project is a student-centered pedagogical approach in which the course instructors take more of a facilitator role guiding students along the way and discussing with them the various issues that might arise, and ultimately evaluating the project deliverables [6].

The “Circuits, Signals, and Measurements” biopotential amplifier lab activity required groups of 2 - 3 students to construct and test a full ECG system on a breadboard to obtain an ECG signal and apply data acquisition principles to evaluate the signal using MatLab. The “Design Methodologies” course expanded on this lab activity by challenging students to, individually, manufacture a functional stand-alone product that incorporated the biopotential amplifier as a PCB. Customer needs and engineering requirements were provided to each student (**Appendix A**). At the conclusion of the project, each student was required to verify the engineering requirements and validate the customer needs.

This project is divided into five stages, which include learning PCB design using DesignSpark, creating a PCB for a biopotential amplifier, soldering all electric components, laser-cutting a housing, verifying the engineering requirements, and validating the customer needs. Deliverables from the first four stages are graded out of 70% while the final demonstration/validation is graded out of 30%. This project accounted for 20% of the total weight of the “Design Methodologies” course. **Appendix B** shows the five stages of the PCB project along with some explanation of how students’ work is assessed at every stage. **Appendix C** shows one anonymous sample of student submission for each of the project stages.

Project Outcomes and Organization

The PCB project is designed in such a way that if a student drops the “Circuits, Signals and Measurements” class, they will still be able to continue taking “Design Methodologies”. In other words, a student’s grade in one class would not impact their performance in the other. Course instructors advised students who were off-cycle or had to drop “Circuits, Signals and Measurements” that they would approach the PCB project from a design perspective and wait until they take “Circuits, Signals and Measurements” to further their understanding of how the circuit functions. Additionally, the biopotential amplifier project in “Circuits, Signals and Measurements” is done in groups of 2 – 3 students while the PCB project in “Design Methodologies” is done individually to 1) give students the chance to build their hands-on skills and 2) make sure that all students understand the design aspects of the circuit.

Student Feedback

At the end of the Fall Quarter of 2021-22 academic year, students (*n = 27*) completed a survey where they rated their confidence in designing, analyzing, and troubleshooting circuits as well as using laser-cutting equipment in a design project (**Figure 1**). Prior to the freshman year, there were some students with prior knowledge of soldering and breadboarding, but most of the students had minimal confidence in their skills in these areas. Additionally, **Figure 1** shows increased confidence in all skills at the conclusion of their sophomore Fall Quarter courses. Overall, the PCB project gave students the ability to reinforce content they learned in "Circuits, Signals, and Measurements" and gain some skills that they would not get from taking the "Circuits, Signals and Measurements" class alone. Some of these skills are PCB design, laser cutting, soldering, and circuit analysis through verification and validation techniques. It also challenged them to design a stand-alone product that must meet certain customer needs. **Appendix D** is a selection of anonymous student feedback that was provided for the "Design Methodologies" course at the end of the quarter through the course feedback system.

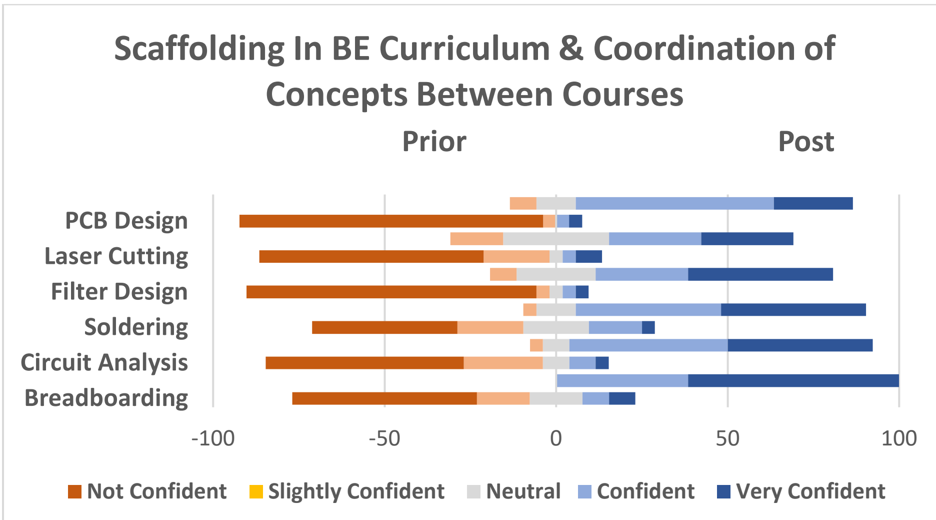

Figure 1. Self-reported student confidence in basic engineering skills prior to freshman year and post sophomore fall courses at RHIT ($n = 27$).

Future Work

Early feedback from students has been positive (**Appendix D**), but some themes have emerged for the faculty to take into consideration in future course offerings: these themes are (1) Instructions & expectations, (2) Timing challenges, and (3) Independence. At this early stage in their circuit and design experiences, the students need clear instructions on the expectations for verification and validation activities. Providing students with clear rubrics and test parameters may help them distinguish between the different stages of design. As for the timing challenge, students worked on the PCB project in the first five weeks, then they started working on another project. The authors believe that running both projects in "Design Methodologies" simultaneously would strengthen the connection between the two courses and allow students to have extended time to complete all project milestones without rushing submissions. Students also needed opportunities to practice their soldering skills and to use the equipment necessary to verify PCB functionality. In the first offering, the instructors worked with each student to verify the functionality of the PCB but noticed that students who developed the skills to complete this task independently were more confident in troubleshooting and redesigning the PCB, if necessary. In future offerings of "Design Methodologies", course instructors will emphasize these skills by incorporating them into the verification and validation requirements.

References

[1] J. A. Beane, “Curriculum Integration and the Disciplines of Knowledge.” *The Phi Delta Kappan*, vol. 76, no. 8, pp. 616–22, 1995. [Online]. Available: http://www.jstor.org/stable/20405413. [Accessed 28 Dec. 2022].

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[3] S.C. Fan, K.C. Yu, K.Y. Lin, “A framework for implementing an engineering-focused STEM curriculum.” *International Journal of Science and Mathematics Education*, vol. 19, no. 8, pp.1523-1541, 2021.

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[5] T. Markham, “Project Based Learning”, *Teacher Librarian*, Vol. 39, no. 2, pp. 38-42, 2011.

[6] M. Aristidou, "Project Based Learning: Are There Any Academic Benefits for the Teacher or Students?," *Journal of Humanistic Mathematics*, Vol. 10, no. 1, pp. 458-471, 2020.

Appendices:

Appendix A. Customer needs and engineering requirements provided by the instructors

Customer Needs
1. Handheld/portable device to measure and analyze an ECG signal in real-time 2. Clearly identified connection should be provided for data collection (i.e., output) 3. Input and output connections are labelled/identifiable 4. Customer should be able to easily change the two 9V batteries used to power the circuit 5. The final device should include an easy-to-access on/off switch 6. The device should be handheld/portable and able to rest on a flat surface 7. The printed circuit board (PCB) should be securely mounted in the enclosure using mounting holes 8. Circuit housing should protect components 9. Device housing should be made of transparent material
Engineering Requirements
1. Must be powered by no more than two 9V batteries 2. Maximum 3.5” x 2.5” footprint for PCB 3. The ECG signal should be acquired using AD620 instrumentation amplifier 4. The ECG signal must be filtered using two 741 operational amplifiers

Appendix B. Student assessment during the various stages of the PCB project.

Stage 1 **Introduction to the DesignSpark Software** - Week 1

- Students are assessed on thier ability to complete a series of tutorial videos to create a PCB.

Stage 2 **Creating a PCB for a Biopotential Amplifier** - Week 2

- Students are assessed on their ability to apply the knowledge learned in "Circuits, Signals, and Measurements" as well as from stage 1 to create a PCB for a biopotential amplifier.

Stage 3 **Soldering Components** - Week 3

- In this stage, students are assessed on their ability to solder electric components to the manufactured PCB. This stage allows students to realize the importance of leaving enough spaces between the componets to make the soldering task easier. They are required to troubleshoot any errors make sure all circuit components are connected correctly.

Stage 3 **Initial Verification** - Week 3

- Students are assessed on their ability to create a PCB that meets all engineering requirements provided to them (**Appendix A**). They check the continuity of all components then they connect the batteries and make sure all components are functional and conneted properly.

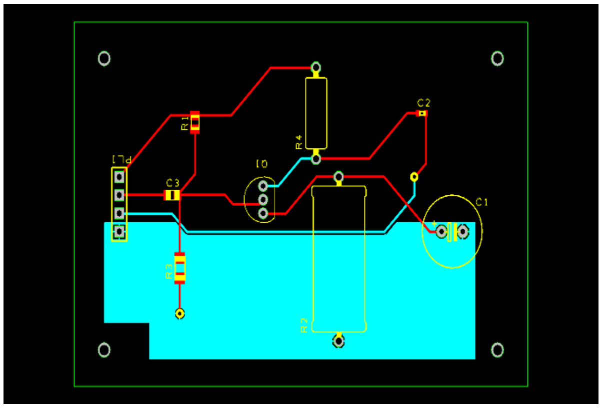
Stage 4 **Desinging and Laser-Cutting a Box for the PCB** - Week 4

- In this stage, students are assessed on their ability to create a housing for the PCB. They are also assessed on taking into consideration how the user would connect inputs and outputs to the device, how easy it is to change the batteries, how accessible the switch is, etc?

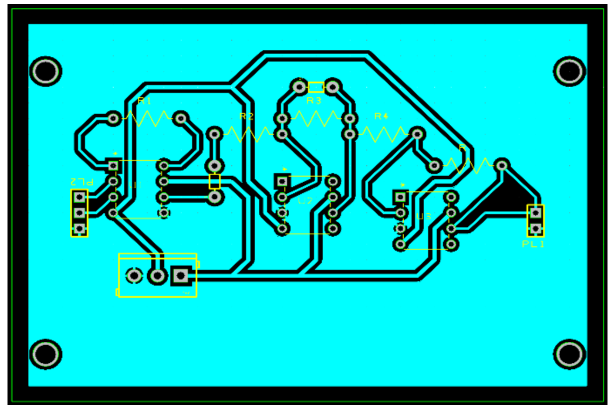
Stage 5 **PCB Validation and Demonstration** - Week 5

- In this final stage, students are assessed on the functionality of their final device to acquire and display an ECG signal on the oscilloscope. **Appendix A** provides a list of the PCB validation checklist (customer requirements).

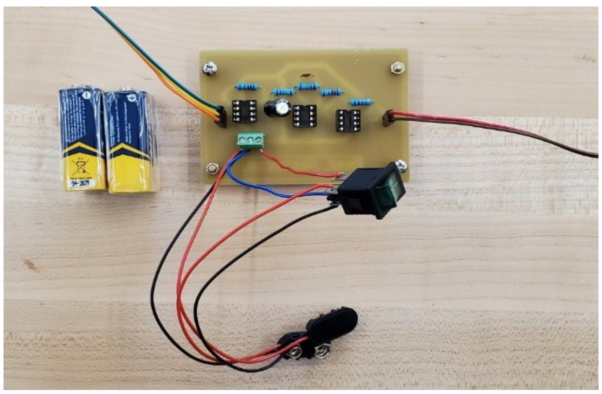
Appendix C. Anonymous sample of student submission for each stage of the PCB project



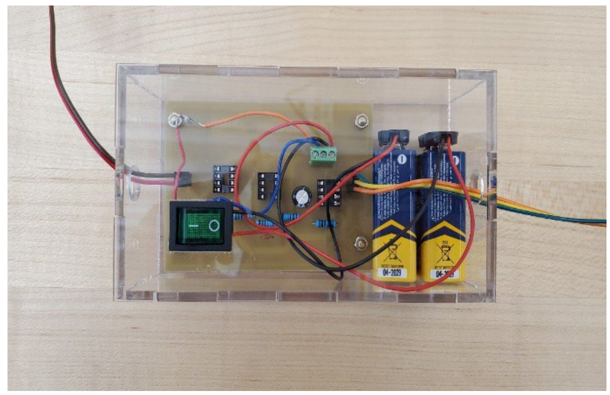
(a)



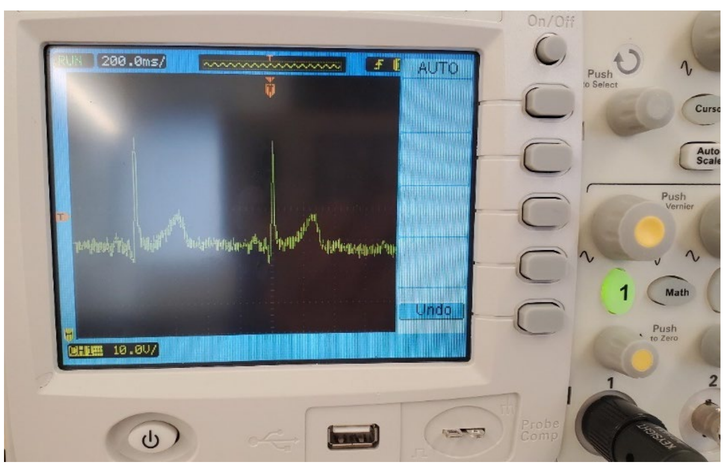
(b)



(c)



(d)



(e)

Anonymous student submission: (a) PCB schematic of the video tutorial series, (b) PCB layout of the biopotential amplifier created in DesignSpark, (c) Manufactured and soldered PCB, (d) PCB secured into laser-cut acrylic housing, (e) ECG signal observed on the oscilloscope.

Appendix D. Comments from Students on the PCB project

1.	I learned a lot about the design process, and I learned valuable skills such as PCB design and prosthetic design that can help me in the "real-world".
2.	Design Methodologies allows you to implement the design process hands on. It also helps integrate what we learned in Circuits, Signals and Measurements with the PCB project. Overall, it helps with better understanding the design process as other skills like soldering, solidworks, and machining.
3.	I learned a lot about the design process, which I feel will help me a lot in my career.
4.	This is a class that really helped me connect the elements of design we learned last year with concepts of circuits and systems.
5.	I feel like I have a good understanding of the FDA design controls process and can apply it to real world situations.
6.	I think it was nice that this class matched up with what we were learning in Circuits, Signals and Measurements.
7.	A strength of this course was being able to apply the design process to the PCB Project and Prosthetic Arm Project.
8.	The projects in this course were very cool. We were walked through the projects with enough guidance to be able to complete the needed tasks, but also enough to allow for interpretation and to add our own spin on the design.