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Advancing Active Learning in Electronics with Customized Printed Circuit Boards

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Abstract

Active, hands-on learning is increasingly vital in engineering education, yet breadboarding poses well-known impediments to students' learning experience. This work addresses breadboarding challenges using customized Printed Circuit Board Assemblies (PCBAs) optimized for core electronics experiments during lectures. The objective is to enhance students' comprehension, engagement, and technical skills compared to traditional breadboarding. The boards feature through-hole mount test points for easy probing, compact layouts focused on specific circuits, and robust soldered components. Students enrolled in the Computer & Electrical Engineering program (CEE) have used the boards in a sophomore-level introductory electronics course titled "Electronics" during lectures on topics including various applications of diodes, BJTs, MOSFETs, op-amps, active filters, oscillators, voltage regulators, and data conversion circuits. Students obtained more accurate results, matching calculations, and simulations compared to using breadboards. In addition, students gained time spent on additional testing and analysis. Students completed assignments using both the customized PCBAs and conventional breadboards. Quantitative and qualitative surveys have been conducted to assess the impact of PCBAs on students' learning experience, technical effectiveness, and educational impact. Student feedback on using PCBAs compared to traditional breadboarding has been analyzed and shared in this paper. The use of custom PCBAs addresses known breadboarding impediments, including loose connections, noise, probing challenges, and cluttered layouts. They reflect fundamental electronic concepts, and therefore, they are reusable, and since most engineering programs require at least one electronics course, they can be shared with other faculty. This paper provides design guidance and student-validated evidence that customized PCBAs can significantly enhance electronic experiments during lecture sessions. Adopting these boards more broadly can empower active learning, allowing students to engage with concepts more directly without the limitations of breadboarding.

Introduction

In addressing the evolving landscape of engineering education, this paper presents a novel educational tool that intersects active learning and practical skill development: customized Printed Circuit Board assemblies (PCBAs). Traditional breadboarding, while foundational, often presents challenges that can obstruct a student's journey from theoretical understanding to practical application, such as unstable connections and convoluted layouts. Our customized PCBAs, optimized for core electronics experiments during lecture sessions, propose a solution through their robust design, featuring easy-to-use test points and streamlined circuit layouts. This study documents the impact of these PCBAs in an introductory electronics course, with the intention of enhancing student engagement, learning experience, and technical abilities. By conducting a comparative analysis of student performance with PCBAs versus breadboards, we aim to evaluate our approach's efficacy. This paper articulates the development and implementation of custom PCBAs, presents the findings from our survey analyses, and discusses the broader implications for active learning in engineering education.

Background /Lit Review

PCBAs are ubiquitous in modern electronics. They are the foundation for assembling electronic circuits in consumer and industrial electronics. PCBAs enable the creation of compact, reliable electronic devices, found in everything from smartphones and laptops to automotive electronics and industrial machinery. Their importance in various sectors highlights the need for engineering students to understand and work with PCBAs through hands-on application [1]. The design of customized PCBAs is typically facilitated by computer-aided design (ECAD) software, which allows for the precise placement of components and optimized circuit layouts [2].
Using customized PCBAs during electronics lectures offers several advantages compared to traditional breadboarding methods. Customized PCBAs provide a more efficient approach to circuit design and construction. Traditional breadboarding often presents students with challenges in managing complex wiring and connections, leading to errors and time-consuming wiring and soldering [3]. Customized PCBAs allow students to focus on the core concepts and analysis of electronics without getting entangled in the intricacies of breadboarding.

Moreover, compared to traditional breadboards, customized PCBAs offer enhanced durability and reliability. Breadboards are susceptible to loose connections and accidental dislodging of components, which can disrupt the functionality of the circuit and hinder the learning process [4]. Customized PCBAs, in contrast, provide a stable and secure platform for circuit assembly, ensuring consistent performance and accurate results [5].

The use of customized PCBs in electronics applications has been shown to significantly improve the accuracy of test results. Traditional breadboarding methods are prone to errors and inconsistencies, which can lead to unreliable experimental data [6]. Customized PCBs eliminate many of these sources of error by providing a stable and reliable platform for circuit assembly [7]

Implementation

The implementation of custom PCBAs in this study was carried out in an introductory electronics course titled "CEE-215 Electronics," which is designed for sophomore students in the Computer & Electrical Engineering program at the University of Wisconsin-Stout. This course is a follow-up to the foundational course titled "CEE-205 Circuit Analysis and Design" and aims to deepen students' understanding of electronic circuits. Key topics covered in the course include diodes, transistors (FETs, BJTs, MOSFETs, JFETs), operational amplifiers (op-amps), and active filters. The course objectives are to analyze semiconductor device circuits, design amplifier circuits, and use simulation tools and laboratory instruments for circuit analysis.

The custom PCBAs are specifically designed for use during in-class activities, not for separate laboratory sessions, allowing students to immediately apply and visualize the concepts discussed in the lecture. They enrich the traditional lecture format and advance students' comprehension of essential topics, the instructor integrates interactive, hands-on activities during the lecture. These exercises are tailored to reinforce the theoretical concepts discussed. The learning activities are designed to engage students and provide dynamic learning experiences that hold their attention by translating theoretical concepts into hands-on experiments. Students can experience and explore concepts presented during the lecture intermittently, and this active engagement ensures that students remain attentive and deeply focused on the subject matter, resulting in a more effective and pleasant learning atmosphere.

A notable example of this approach is evident when exploring the full bridge rectifier in lectures. The instructor facilitates a practical exercise where students assemble a basic power supply circuit comprising a transformer, a full-bridge rectifier, and a voltage regulator. Students then measure the voltage at various stages: pre- and post-transformer, post-rectifier, post-capacitor, and post-voltage regulator. This exercise allows students to see the practical application of concepts addressed in the lecture. However, the time-intensive nature of assembling components on a breadboard and fixing any ensuing issues consumes most of the time for the exercise. The introduction of custom PCBAs is a strategic response to this challenge. Custom PCBAs provide a more streamlined and accurate platform for student activities integrated within lectures. By presenting students with ready-made PCBAs, complete with schematics and layouts as seen in Figures 1, 2, and 3, the instructional focus shifts from constructing to analyzing circuits. This shift streamlines the educational process and allows students to interact directly with the electronic components, immediately applying theoretical knowledge and achieving precise, reliable measurements. The incorporation of custom PCBAs is designed to fix the common complications associated with breadboards, strengthen the dependability of experimental data, and improve students' understanding and confidence in dealing with actual electronic circuits. This methodological innovation aligns with the educational goal of increasing student engagement and effectively bridges the gap between theoretical learning and practical application—a critical component of engineering education.

Curriculum-Based Board Selection

Common US college textbooks covering topics like diodes, transistors (JFET, BJT, MOSFET), op-amps, active filters, and basic power electronics were analyzed. This analysis informed the choices for the custom board designs for the introductory electronics course. To cover fundamental concepts, 21 boards are designed, some manufactured (11), and introduced in the classroom (7); see Table 1.

1. **Board Design Considerations:**
    - Ease of Probing: Integration of test points for all significant measurement points. This design choice facilitates easy and reliable connection of probes for voltage or current measurements.
    - Board Size: Balancing realistic representation and providing clear visibility of wiring and components. Designed to allow students to easily identify different components.
    - Visual Appeal: Ensuring that the boards are aesthetically pleasing to engage students.

2. **Simplicity and Clarity:**
   - Ensuring the boards remain basic and clear, avoiding additional circuitry and components that could confuse beginners, see Figure 1, 2, 3.
   - Emphasizing fundamental concepts and clear patterns in circuit operation.
   - 21 boards are designed to visualize fundamental electronics concepts associated with course objectives and course content.

3. **Safety Features:**
   - Inclusion of measures to prevent direct contact with AC power points.
   - Ensuring components like transformers are fully enclosed.
   - Providing protective casing for high-power boards to minimize accidental contact with high-voltage points.
   - Rounded board corners to prevent physical injury during handling.
   - Provide a board container that protects the board during transport and storage and serves as a stable base during measurements, see Figure 6, 7.

4. **Sustainability and Durability:**
   - Selection of high-quality connectors, parts, and PCB materials to extend the usable life of the boards.
   - Use of Surface-Mount Device (SMD) components that are not excessively small, allowing for easy repairs and replacements by technicians or students.
   - Providing protective housing that adds longevity to the custom PCBAs.

5. **Cost-Effectiveness:**
   - Focusing on continuing reuse of the boards to ensure minimal waste.
   - Designing the boards to be a cost-effective solution compared to similar commercial products.
   - Building the protective housing in collaboration with faculty knowledgeable in parametric modeling and additive manufacturing, see Figure 6, 7.

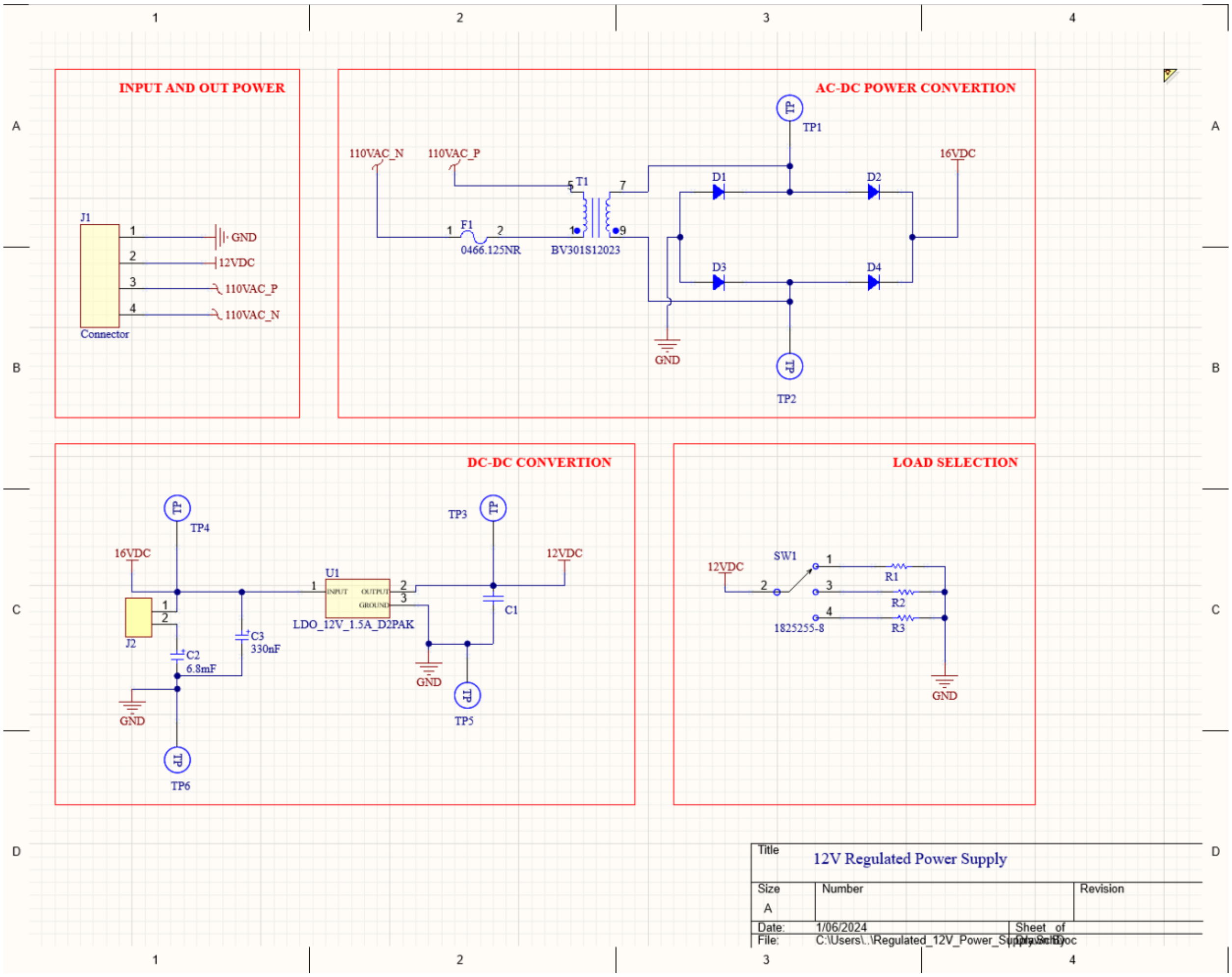

Figure 1. 12V Regulated Power Supply Schematic (by author)

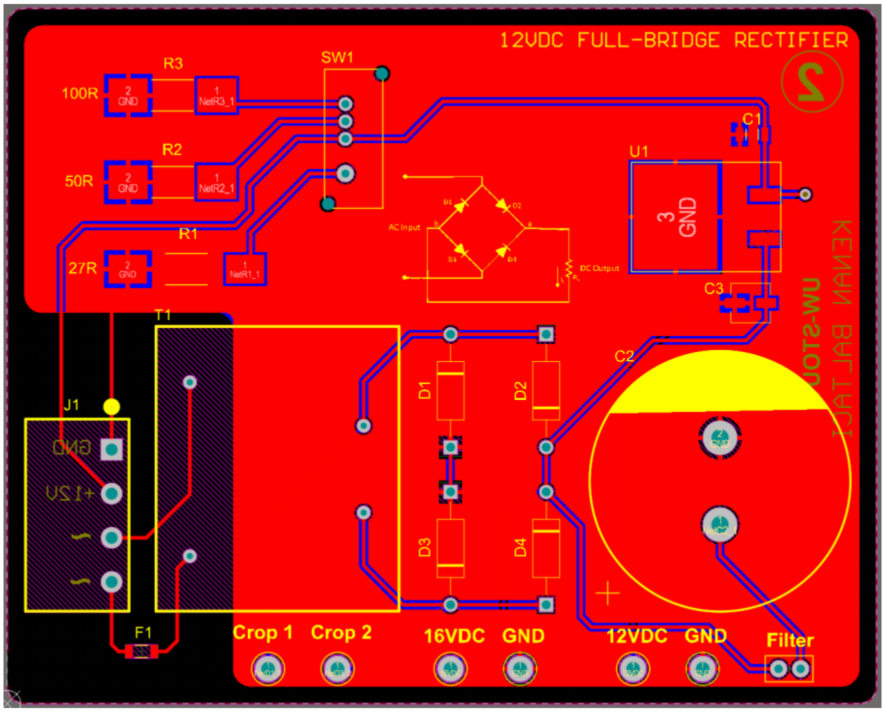

Figure 2: 12V Regulated Power Supply 2D PCB Layout

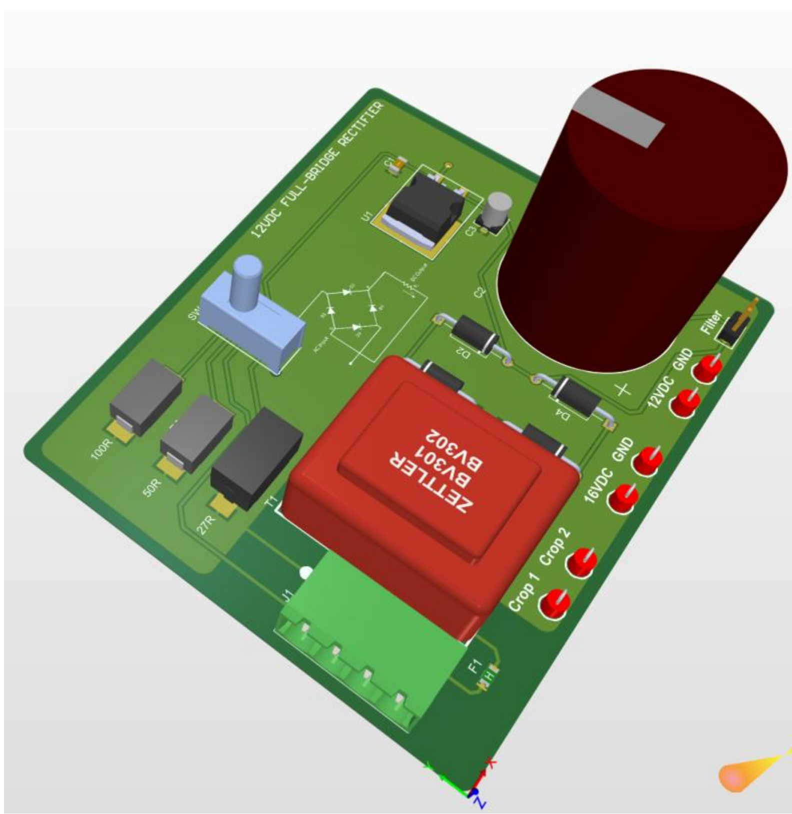

Figure 3: 12V Regulated Power Supply 3D PCB Layout

Table 1. List detailing design completion, manufacturing, and classroom usage of instructional custom PCBAs.

	Designed	Manufactured	Used in Class
Rectifiers			
Half Bridge Rectifier	✓	✓	✓
Full Bridge Rectifier	✓	✓	✓
12V Rectified Power Supply	✓	✓	✕
BJT (Bipolar Junction Transistor) Amplifiers			
Common Emitter BJT Amplifier	✓	✓	✓
Common Base BJT Amplifier	✓	✓	✕
Common Collector BJT Amplifier	✓	✕	✕
Power Amplifier Circuit Board	✕	✕	✕
FET (Field Effect Transistor) Amplifiers			
Common Source FET Amplifier	✓	✓	✓
Common Drain (Follower) FET Amplifier	✓	✓	✕
Common Gate FET Amplifier	✓	✕	✕
Pre-Amplifier Circuit Board	✕	✕	✕
pH Sensor Circuit	✕	✕	✕
Operational Amplifier (Op-Amp) Circuits			
Inverting and Non-Inverting Op-Amp Amplifier	✓	✓	✓
Summing Op-Amp Amplifier	✓	✓	✕
Integrators and Differentiators Op-Amp Amplifier	✓	✕	✕
Instrumentation Amplifier	✓	✕	✕
Active Filters			
Active Low-Pass Filter	✓	✓	✓
Active High-Pass Filter	✓	✓	✓
Active Band-Pass Filter	✓	✕	✕
RFID Reader Board	✕	✕	✕
Voltage Regulators			
Variable DC Power Supply	✕	✕	✕

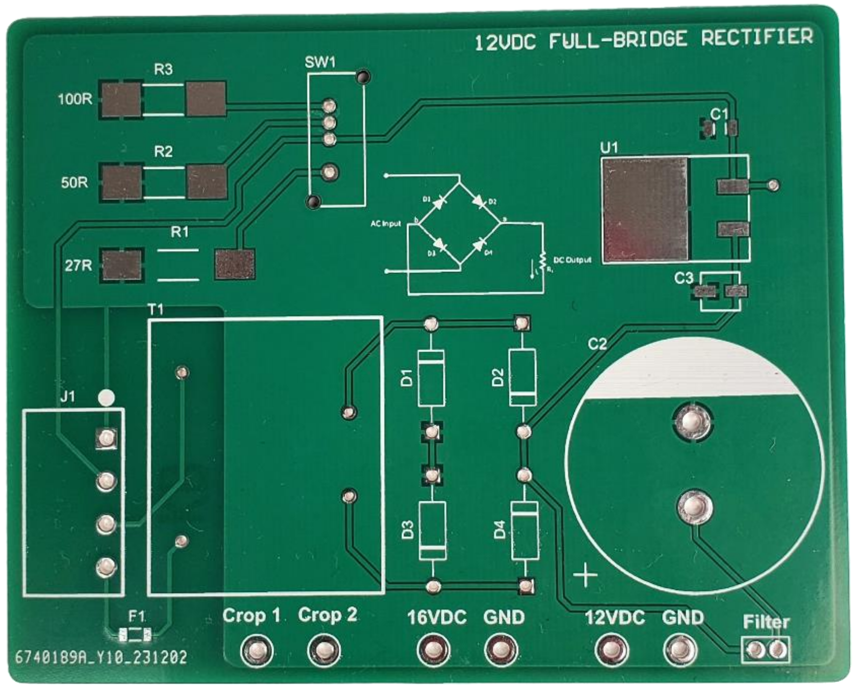

Figure 4. Manufactured PCB (external provider)

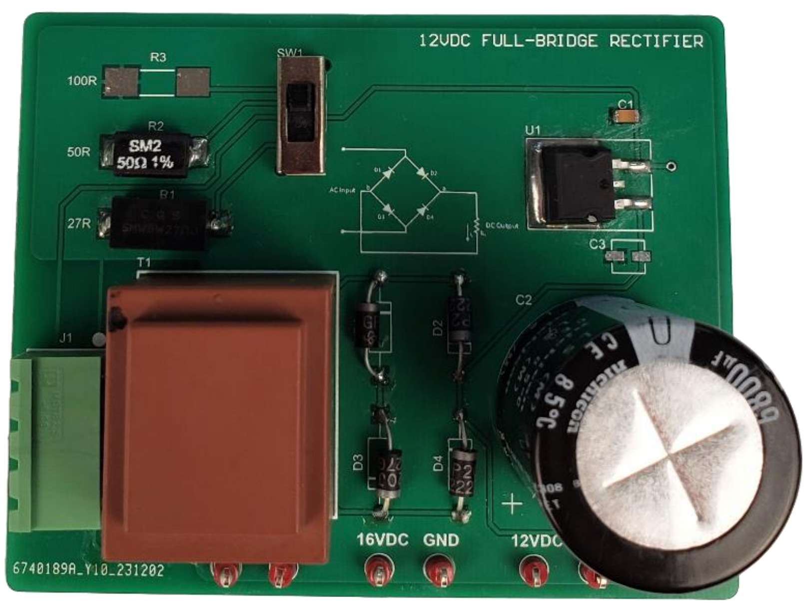

Figure 5. Components soldered on PCBA by a student lab assistant.

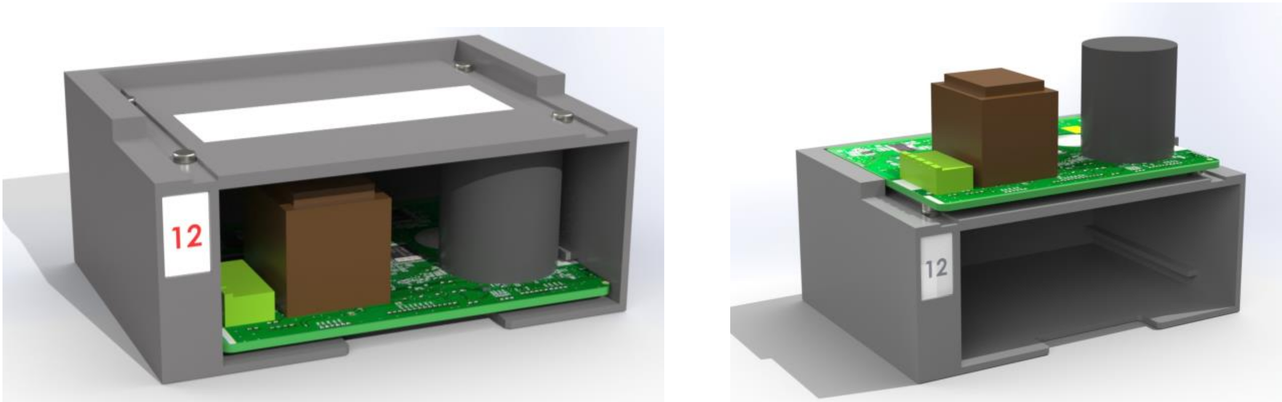

Figure 6. Protective housing for custom PCBA (design renderings).

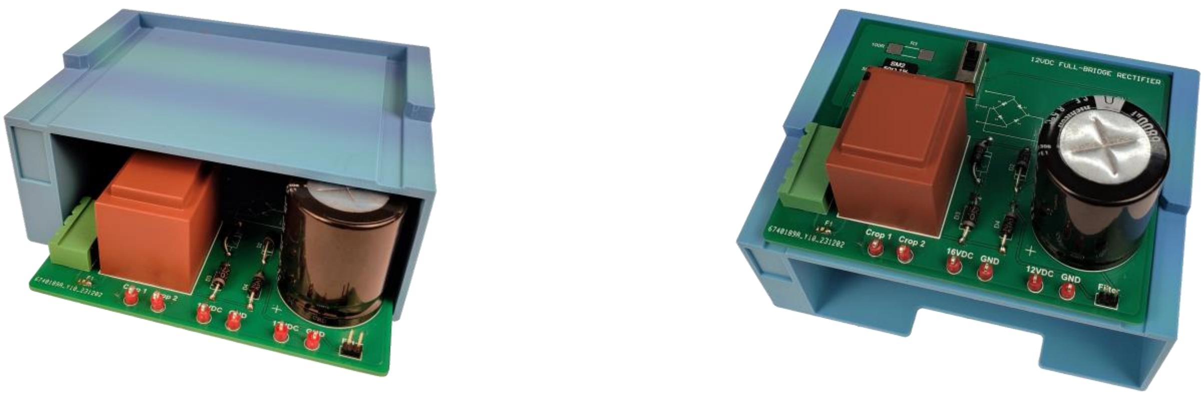

Figure 7. Protective housing and work tray with custom PCBA (prototype).

Curriculum Adoption and Outcome Measurement

Students worked with seven custom PCBAs throughout the semester, and the remaining concepts were applied to traditional breadboarding. To facilitate the survey, the instructor chose the lecture on full-bridge rectifiers.

A structured survey was conducted to quantitatively assess students' experiences and perceptions regarding the use of custom PCBAs. The survey was conducted in the foundation course for CEE students with 15 participants. The instructor lectured on full-bridge rectifiers and solved an exercise problem on the board about the full-bridge rectifiers. Then, students were asked to build the same circuit in the exercise problem solved with a breadboard comprising a transformer, a full-bridge rectifier, and a voltage regulator. Following the activity instructions, students were asked to measure the voltage at various stages: pre- and post-transformer, post-rectifier, post-capacitor, and post-voltage regulator. Then, they compare the results they got from measurements and results from the problem calculation and discuss the results. Then, students were asked to repeat the practical exercise with a power supply PCBA board, which has the same circuitry. Finally, students were surveyed on their experience doing the in-class activities with breadboard and custom PCBA board.

The survey included 15 questions covering various aspects of students' interaction and learning experience with custom PCBAs. Students were instructed to rate their level of agreement with each statement using a 10-point Likert scale, where a score of 1 corresponds to 'Strongly Disagree' and a score of 10 denotes 'Strongly Agree.'

Implementing the Likert scale allows for a nuanced capture of students' attitudes, ranging from strong disagreement to strong agreement, thereby facilitating a detailed understanding of their experiences. The survey distribution targeted students who have engaged with custom PCBA and traditional breadboards, ensuring that the feedback obtained was relevant and grounded in actual usage experiences.

After the data collection phase was completed, the responses were analyzed. This analysis involved examining the mean scores, distribution patterns, and other statistical measures to extract meaningful insights and discern prevailing trends in students' perceptions.

The findings from this survey not only highlight key insights and patterns but also suggest actionable recommendations. These insights are crucial for informing future pedagogical strategies, curriculum development, and resource allocation aimed at enhancing the effectiveness of custom PCBA boards as a learning tool in engineering education.

The Institutional Review Board (IRB) has determined that this project, 'Advancing Active Learning in Electronics with Customized Printed Circuit Boards,' is exempt from review by the IRB for the Protection of Human Subjects. Microsoft Word Editor and Grammarly tools were used to review spelling, grammar, punctuation, and clarity.

Result and Discussion

The data in Table 2 revealed that students found the overall experience with custom PCBAs to be highly positive, with a mean rating of 8.23, indicating a favorable reception. Ease of learning and use were similarly rated highly, with a mean of 8.31, suggesting that custom PCBs were indeed more user-friendly. Clarity of instructions received a lower mean score of 7, indicating that while effective, there may be room for improvement in the communication of usage guidelines. Notably, the custom PCBAs' impact on time efficiency during setup was rated the highest, with a mean of 8.85, reflecting a significant enhancement in lab activity flow. Additionally, the reduction in errors or troubleshooting needs was also rated highly, with a mean of 8.77, underscoring the PCBAs' reliability and the subsequent improvement in experimental outcomes. The median scores for each question are closely aligned with the mean, reinforcing the central tendency of the data. Modes were consistently high, frequently occurring at the upper end of the scale, further corroborating the overall positive response. The standard deviation across the questions ranged from 1.24 to 2.04, indicating a moderate response spread. The minimum scores varied from 4 to 7, while the maximum scores were consistently at 10, highlighting a few outliers who may not have shared the same positive experience as the majority.

Table 2. Student ratings on the effectiveness of custom PCBAs in enhancing the learning experience.

Q#	Question	Mean	Median	Mode	Std. Dev.	Min	Max
Theme 1: Usability and Learning Experience, see Figure 8							
1	I found the overall experience using the custom PCBA significantly better than using the traditional breadboard.	8.23	8	8	1.48	5	10
2	The custom PCBA was easier to learn and use compared to the breadboard.	8.31	8	8	1.49	5	10
3	The instructions provided for using the custom PCBA were clear and understandable.	7	7	8	2.04	4	10
6	The quality of the results obtained using the custom PCBA was superior to those obtained with the breadboard.	7.54	8	10	2.26	3	10
Theme 2: Efficiency and Performance, see Figure 9							
4	The custom PCBA saved time in setting up and completing the lab exercises compared to the breadboard.	8.85	9	10	1.63	5	10
5	I noticed a significant decrease in errors or issues while using the custom PCBA compared to the breadboard.	8.77	9	10	1.24	7	10
13	I would recommend the use of custom PCBAs to other students or educators based on my experience.	8.38	8	8	1.45	6	10
Theme 3: Educational Impact: Questions, see Figure 10							
7	The custom PCBA was more comfortable and ergonomic to use than the breadboard.	8.23	8	8	1.42	5	10
10	The custom PCBA encouraged me to develop or apply problem-solving skills more effectively than the breadboard.	6.85	8	8	2.94	1	10
14	The use of custom PCBAs significantly improved my efficiency and understanding in lab exercises.	8.15	8	8	1.72	4	10
15	My troubleshooting skills were better enhanced using the custom PCBA board compared to the breadboard.	6.38	6	6	2.22	3	10
Theme 4: User Preference and Recommendation, see Figure 11							
8	Using the custom PCBA enhanced my learning and understanding of the lab concepts.	7.46	7	10	2.44	4	10
9	The custom PCBA was more durable and reliable than the breadboard.	8.77	10	10	1.88	4	10
11	The custom PCBA better prepared me for real-world applications than the breadboard.	7.23	8	10	2.74	2	10
12	I would prefer to use the custom PCBA board in future lab exercises over the breadboard.	8	8	10	2.16	4	10

In conclusion, the survey data supports the hypothesis that the integration of custom PCBs into the electrical engineering curriculum enhances the learning environment by streamlining the practical application of theoretical concepts. The findings suggest that students benefit from the use of custom PCBAs, experiencing a more engaging and efficient educational process.

The fifteen (15) survey questions can be categorized into four themes addressing aspects of performance and student experience. The themes are:

Theme 1: Usability and Learning Experience: Questions 1, 2, 3, and 6

Theme 2: Efficiency and Performance: Questions 4, 5, and 13

Theme 3: Educational Impact: Questions 7, 10, 14, and 15

Theme 4: User Preference and Recommendation: Questions 8, 9, 11, and 12

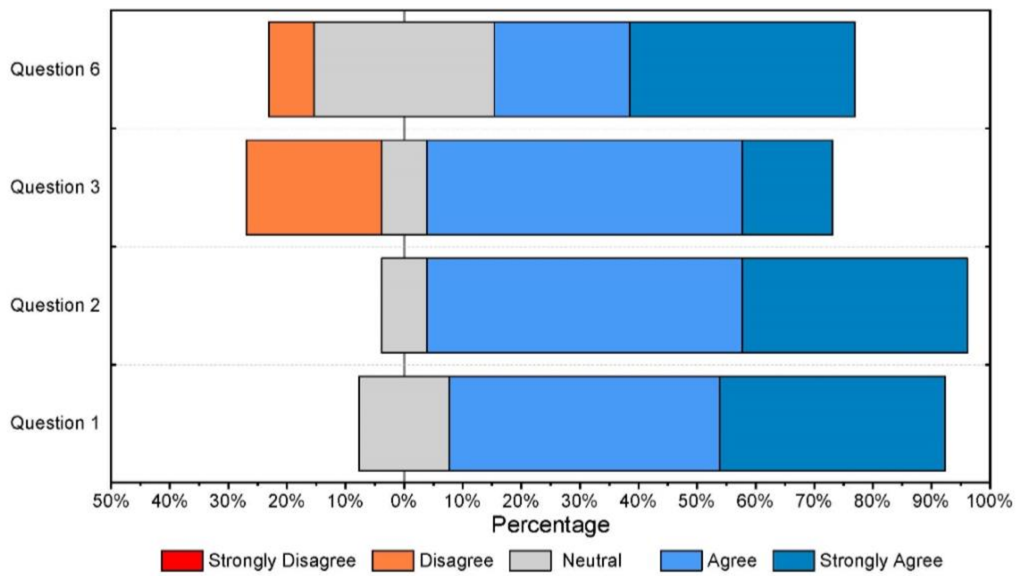

Figure 8. Theme 1: Usability and Learning Experience: Questions 1, 2, 3, and 6.

Figure -8 presents positive student feedback on the usability and learning experience with custom PCBAs. Most responses indicate that students found the boards easier to learn, and use, compared to breadboarding. This suggests that custom PCBAs are not only more user-friendly but also enhance the overall learning experience in lab sessions.

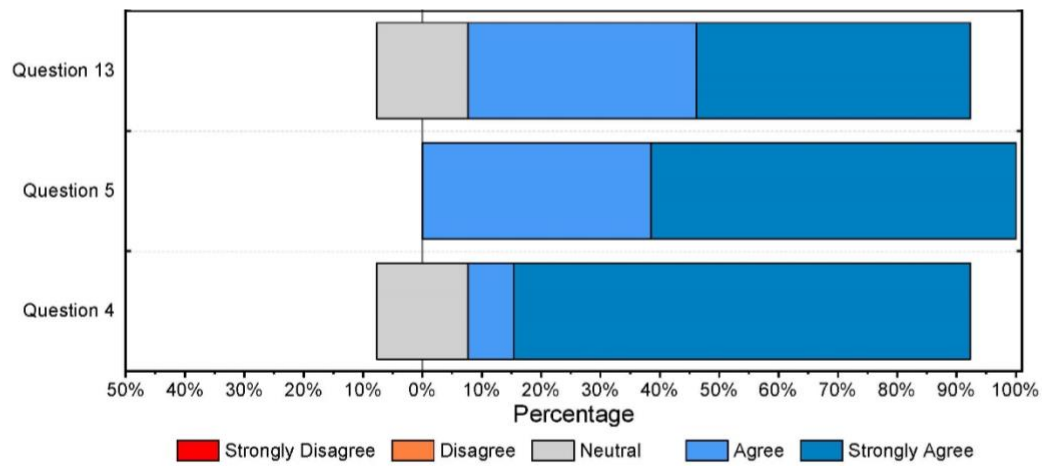

Figure 9. Theme 2: Efficiency and Performance: Questions 4, 5, and 13.

In Figure 9, the focus is on the efficiency and performance improvements offered by custom PCBAs. Students reported considerable time savings and a reduction in errors during analysis exercises. These findings highlight the boards' role in streamlining lab activities and allowing more efficient use of class time.

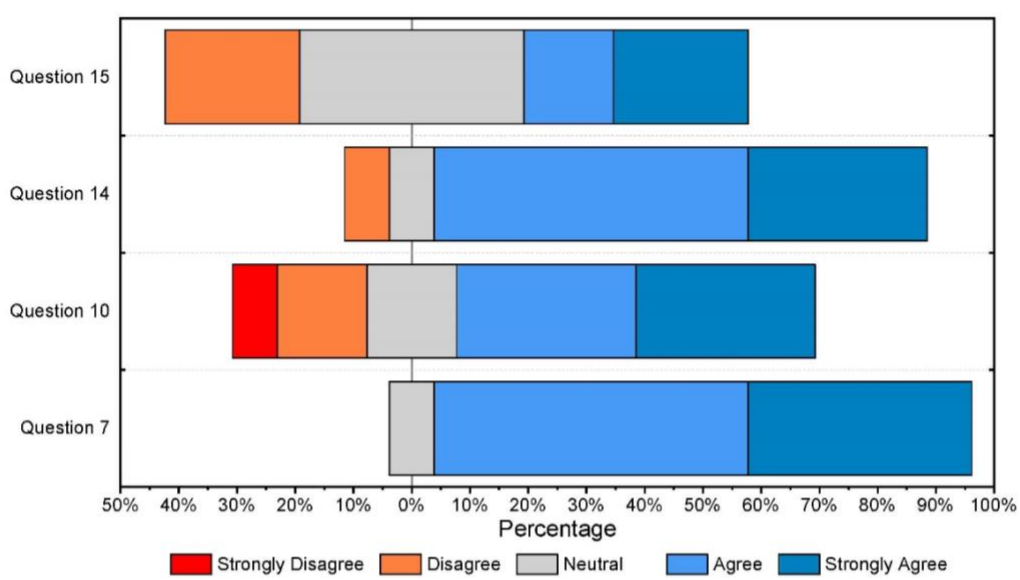

Figure 10. Theme 3: Educational Impact: Questions 7, 10, 14, and 15.

Figure 10 shows the educational impact of the custom PCBAs, with students expressing positive feedback on several aspects. Question 7 highlights that students found the custom PCBAs more comfortable and ergonomic to use than traditional breadboards, which likely contributed to a more engaging and efficient learning environment. Question 14 further underscores this point, with students acknowledging that the use of custom PCBAs significantly improved their efficiency and understanding of lab exercises. While the survey data indicates lower means for questions related to problem-solving and troubleshooting skills (questions 10 and 15), it's important to note that the primary focus of the custom PCBAs is not on directly improving these skills. Instead, the custom PCBAs are designed to facilitate a deeper comprehension of electronic concepts and provide a more efficient learning experience by reducing the time spent on breadboarding and troubleshooting common issues. The development of problem-solving and troubleshooting skills is addressed through other components of the curriculum, ensuring a comprehensive educational approach. In retrospect, the wording of these two questions was not a good choice.

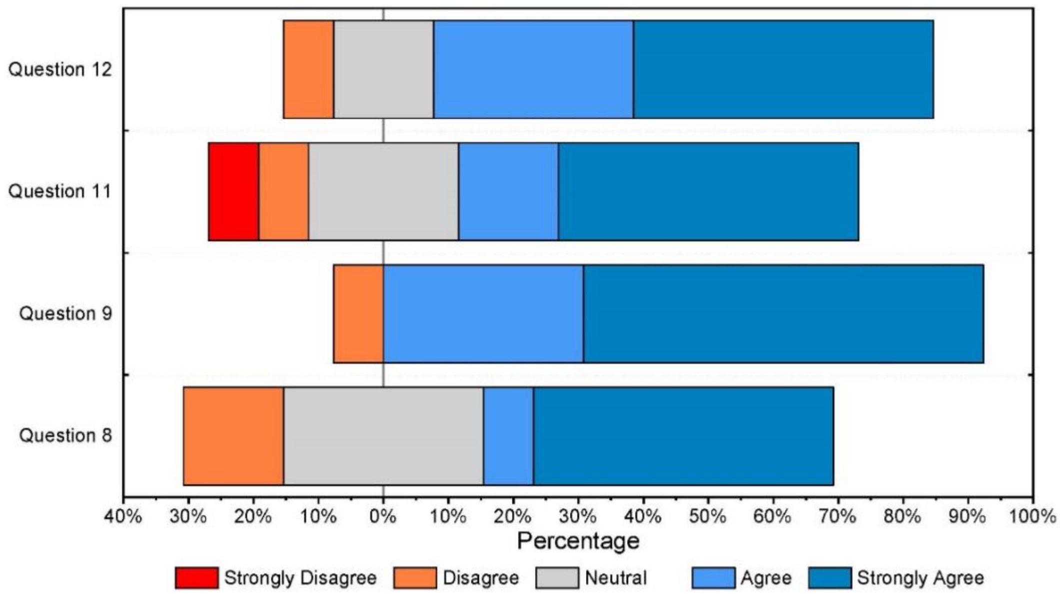

Figure 11. Theme 4: User Preference and Recommendation: Questions 8, 9, 11, and 12.

Figure 11 illustrates students' strong preference for custom PCBAs and their willingness to recommend them to others. This preference indicates the boards' perceived advantages over traditional breadboards, particularly in enhancing hands-on experiences and learning outcomes.

In this study, we focused on assessing students' perceptions of their experiences with custom PCBAs, rather than directly measuring their learning outcomes. We acknowledge this as a limitation. However, we believe that custom PCBAs indirectly enhance student learning. By eliminating the time-consuming breadboarding process, students can spend more time engaging with the material and applying what they've learned. This efficient use of class time allows for a deeper exploration of topics and more in-class activities. Additionally, by reducing the need for troubleshooting common issues associated with breadboarding, students can concentrate more on the core learning objectives. In future studies, we plan to directly measure the impact of custom PCBAs on student learning to provide a more comprehensive evaluation of their effectiveness.

Conclusion

This paper details the implementation and effects of integrating custom PCBAs into an introductory electronics course. These custom PCBAs are integrated into lectures as in-class activities to provide immediate, hands-on learning experiences. This approach aims to enhance student engagement and comprehension by allowing them to apply lecture concepts in real-time. Using PCBAs in this manner offers a dynamic break from traditional lectures, promoting active learning and helping students to better grasp complex electronic principles through direct interaction and experimentation. This teaching method shows significant potential in improving the overall effectiveness and enjoyment of learning in electronics courses.

The survey results indicate a highly positive reception of custom PCBAs among students in an introductory electronics course. Students found the PCBAs to be more user-friendly and efficient than traditional breadboarding methods for in-class activities, with particularly high ratings for ease of use and time efficiency. However, there was room for improvement in the clarity of instructions for using the PCBAs, suggesting a need for more detailed guidelines or tutorials. Overall, the survey supports the effectiveness of custom PCBs in enhancing the learning experience in electronics education.

The authors plan to enhance the custom PCBAs used in their electronics course based on student feedback. Future improvements will focus on redesigning the PCBAs' visuals, particularly the silkscreen, to more effectively guide students in probing and component identification.

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