2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #53420

Integrating Digital Electronic Concepts in Electro-Mechanical Engineering Technology Education through Experimental- Centric Pedagogy

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Abstract

The Electro-Mechanical Engineering Technology (EMET) program is designed to meet the growing demand for engineers in rapidly developing fields such as industrial automation, robotics, and smart manufacturing. This multidisciplinary program equips students with a strong foundation in both electrical and mechanical engineering principles, enabling them to design, develop, and test computer-controlled mechanical systems used in modern industry. To better prepare students for real-world applications, the EMET curriculum has adopted active learning strategies that focus on engaging students through practical, hands-on experiences.

One such approach is Experimental-Centric Pedagogy (ECP), which emphasizes learning by doing and integrates laboratory work directly into the learning process. This paper presents an ongoing effort to incorporate digital electronics concepts into ECP using the ADALM2000 Active Learning Module, a portable and affordable lab device that allows students to experiment outside of traditional lab settings.

As part of this initiative, EMET students participated in a project to design and build a 4-bit register using D flip-flop integrated circuits (ICs) and the ADALM2000 platform. Prior to beginning the project, students studied essential topics such as flip-flops, counters, and registers in their Digital Electronics course. They were also introduced to Scopy software, which enabled real-time visualization and analysis of electronic signals during the experiment.

The hands-on nature of the project allowed students to connect theoretical knowledge with real-world applications, reinforcing their understanding of digital logic design. The project was carried out during the Spring 2025 semester, and all participating student groups took part in informal post-project interviews. Feedback from these interviews revealed high levels of engagement, enthusiasm, and a strong interest in working on additional projects using modern tools and instrumentation. Students also reported improved confidence in applying what they had learned in a practical setting.

In conclusion, this study demonstrates that integrating portable laboratory tools and active, experiment-based learning methods can significantly enhance learning outcomes for undergraduate students in EMET programs. By making engineering concepts more tangible and accessible, this approach supports student motivation, improves technical skills, and better prepares graduates for the demands of the engineering workforce.

Introduction

Engineering education has increasingly shifted toward active, student-centered pedagogies that emphasize experiential and evidence-based learning. Among these, hands-on and experiment-centric approaches have shown strong potential in improving student engagement, conceptual understanding, and motivation across a wide range of engineering disciplines. Prior work has demonstrated that hands-on learning pedagogy enhances students' ability to grasp complex concepts in transportation infrastructure systems, particularly in analysis, design, and maintenance contexts [1], [2], [3].

Experiment-Centric Pedagogy (ECP) has emerged as a promising framework that integrates structured experimentation into the learning process. Studies across disciplines—including civil engineering, computer science, digital electronics, and chemistry—have reported improvements in student learning outcomes, critical thinking, and motivation when ECP is implemented [4], [5], [6], [7]. For example, ECP-based approaches in digital electronics courses have shown that using printed circuit boards (PCBs) significantly enhances learning compared to traditional methods [8]. Similarly, experiment-focused teaching in computer architecture courses has yielded measurable improvements in student comprehension and performance [9], [10].

Beyond discipline-specific gains, research also highlights the broader cognitive and affective benefits of hands-on and experiment-driven instruction. These include reductions in test anxiety, increases in student motivation, and improvements in critical thinking skills [5]. Performance-based and hybrid learning models further complement these approaches by enabling flexible yet rigorous engagement with engineering concepts, as demonstrated in thermodynamics education [11]. Additionally, the use of portable and cost-effective laboratory instrumentation has expanded access to hands-on learning, allowing students to actively participate in experiments both inside and outside traditional laboratory settings [12], [13].

The effectiveness of these pedagogical approaches has also been explored in diverse learning environments, including remote and hybrid formats. Comparative studies indicate that while in-person labs remain valuable, well-designed remote or portable lab experiences can achieve comparable learning outcomes [14]. Furthermore, integrating structured management frameworks and tools can support the successful implementation of large-scale, multi-departmental STEM education initiatives that incorporate these pedagogies [15].

Despite these advances, there remains a need to further investigate how experiment-centric and hands-on learning approaches can be systematically integrated into engineering curricula to maximize student learning and engagement. This study builds on prior work by exploring, implementing, and innovating, with the goal of advancing effective pedagogical practices in engineering education.

Background

- **Registers and Flip-Flops**

Registers store binary data in digital systems. A 4-bit register uses four flip-flops working together.

A D flip-flop stores the input value when a clock signal changes. A JK flip-flop can be connected to act like a D flip-flop. In this project, students connected:

- D to J
- Inverted D to K

This setup makes the JK flip-flop behave like a D flip-flop.

- **Portable laboratory tool**

The ADALM2000 (M2K) is a small, USB-powered laboratory device. It works with Scopy software and provides:

- Logic analyzer
- Signal generator
- Oscilloscope
- Power supply

Traditional laboratories require several large and expensive instruments. The M2K combines these tools into one portable device. It is lower in bandwidth than high-end equipment but is sufficient for undergraduate digital logic experiments.

Figure 1. The ADALM2000 (M2K) active learning module

Purpose of the Study

This study addresses two main questions:

- Can portable hardware tools improve student understanding of digital logic?
- Can measurable learning gains be shown using structured assessment?

The goal is not to replace embedded controllers, but to strengthen students' understanding of hardware before they use software-based systems.

Methodology

- **Participants**

The study was conducted in Spring 2025 in a Digital Electronics laboratory course. There were 13 students in the class. Students worked in four groups.

- **Laboratory activity**

Students built a 4-bit register using SN74LS109AN JK flip-flops on a breadboard.

The M2K was used to:

- Provide input signals
- Generate clock pulses
- Monitor output signals

Channel assignments were:

- Digital I/O 0–3: Inputs
- Digital I/O 4: Clock
- Digital I/O 8–11: Outputs

Students used Scopy's logic analyzer to observe and confirm correct register operation.

- **Student tasks and responsibilities**

Students were not required to design the register from scratch. The circuit structure was provided by the instructor. This allowed students to focus on understanding and implementation instead of high-level design.

However, students were responsible for:

- Reading and understanding the circuit diagram
- Wiring the flip-flops correctly
- Configuring JK flip-flops as D flip-flops
- Connecting the circuit to the M2K
- Setting up input and output channels
- Testing clock and input patterns
- Troubleshooting wiring and signal problems

This structured approach helped students focus on flip-flop behavior, clock timing, and hardware testing skills.

- **Learning outcomes**
  The following learning outcomes were assessed:

- Explain how JK and D flip-flops work
- Convert a JK flip-flop into a D flip-flop
- Build and test a 4-bit register
- Understand clock timing in sequential circuits
- Troubleshoot digital circuits
- Use laboratory tools to test circuits

- **Assessment methods**
  Students were given an informal 10-question oral quiz before and after the project

Measure	average score
Pre-Quiz	62%
Post-Quiz	84%
Improvement	+22%

Table 1. Average student scores on the informal 10-question oral quiz before and after the 4-bit register project

Performance rubric

Each group was graded using a rubric (0–4 scale):

Category	Average Score
Circuit works correctly	3.8
Correct flip-flop configuration	3.6
Troubleshooting ability	3.5
Proper use of tools	3.6

Table 2. rubric scores for each performance category in the 4-bit register project (0–4 scale)

Average total score: 14.5 out of 16.

Student interviews

Short group interviews were conducted after the project. Students reported:

- Better understanding of hardware behavior
- Increased confidence in troubleshooting
- Higher engagement during the lab

Results and discussion

- All groups successfully built and tested the 4-bit register. Some groups experienced wiring problems at first, but they solved these problems through testing and debugging.
- The 22% improvement in quiz scores shows clear learning gains. High rubric scores show that students were able to apply what they learned.
- Students said that building the register helped them understand what happens inside digital systems. Many said this hands-on experience made the theory clearer.
- The results show that portable hardware tools can strengthen learning and complement embedded controller instruction.

Limitations

- Small class size (13 students)
- No comparison group
- Short-term assessment

Future studies will include larger groups and comparison with software-only instruction.

Conclusion

This study examined the use of the ADALM2000 (M2K) in a digital electronics laboratory course using an Experimental-Centric Pedagogy approach.

Results show:

- Measurable improvement in student understanding
- Strong performance in building and testing circuits
- Increased confidence and engagement

Portable laboratory tools can improve hands-on learning and help students better understand digital hardware before moving to embedded systems.

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