EVALUATION OF THE IMPACT OF DIGITAL LABORATORY ON TEACHING AND LEARNING IN BASIC ELECTRONICS

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Abstract

Electronics and technology have become integral parts of our daily lives and constantly evolve. Adapting to these changes and incorporating the latest advancements into their curricula can be challenging for higher educational institutions. It requires staying updated with the latest technologies and developing relevant coursework and practical training opportunities for students. This includes implementing online learning platforms, video conferencing tools, virtual classrooms, and interactive learning materials. Validation processes play an essential role in maintaining the quality and accuracy of digital resources, and educators should critically evaluate the credibility and reliability of these resources.

This study examines the impact of incorporating a digital laboratory in the Basic Electronics course at the University of Almeria across five academic years. The transition from traditional classes in-person to remote and hybrid models was necessary due to the COVID-19 pandemic, which led to the integration of digital tools. The analysis focuses on the practical components of the course. It compares various teaching models: face-to-face, face-to-face and virtual with digital lab support, entirely virtual with digital lab, and a hybrid model. The results indicate that including a digital laboratory enhances student success rates in practical sessions but has limited influence on the overall course success rate. Years with virtual teaching saw higher absenteeism. The hybrid model, combining face-to-face teaching and digital laboratory, proved to be the most effective in improving both pass rates and grades. The study highlights the importance of better balancing digital laboratory usage and in-person learning to prepare engineering students for a rapidly changing job market.

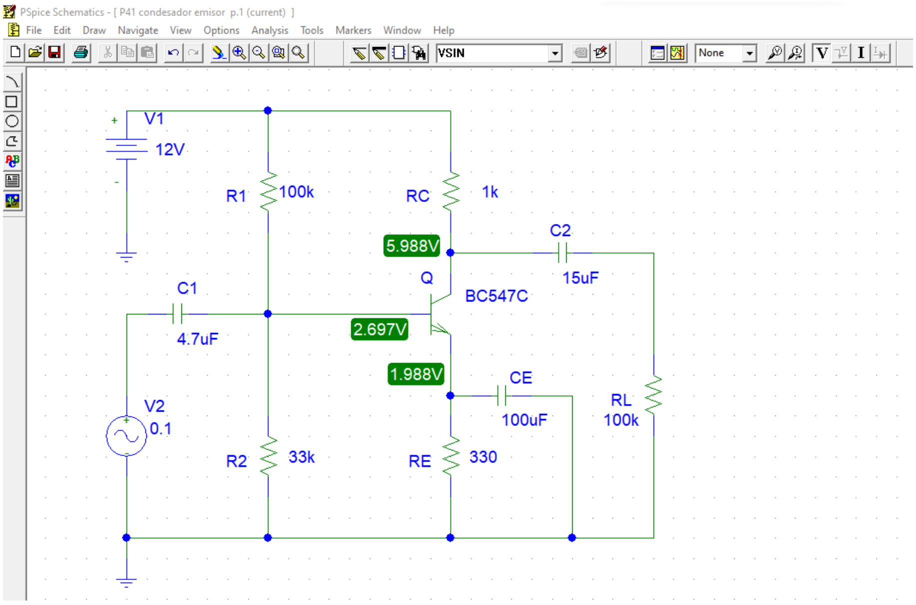
Keywords: Digital Laboratory, Electronics, Engineering, Flipped Learning.

1 INTRODUCTION

The COVID-19 pandemic disrupted traditional education, and universities had to adapt quickly to online learning platforms and tools [1], often needing adequate planning [2], leading to certain challenges. The major hurdles included disparities in access to devices and the internet [3], particularly for disadvantaged students, a lack of digital skills among educators and students [4], complex online assessment strategies [5], and issues with time management and the quality of online education. These deficiencies can be addressed through dedicated online programs that foster active teaching methods and encourage student participation [6].

For engineering education, which emphasizes hands-on experience, digital laboratories have become vital. Virtual environments enable students to design, analyze, and simulate electronic circuits, thus facilitating experimentation and the development of engineering skills. Digital environments offer new possibilities for teaching and learning, and the continuous evolution of teaching paradigms reflects the changing landscape of education [7]. These virtual tools enhance the learning experience and help students to increase their confidence in the essential skills required in engineering curricula [8]. Simulators with graphical interfaces (Figure 1a) were the forerunners of digital laboratories (Figure 1b), the latter improving over the former by providing interactive platforms to manipulate virtual instrumentation, allowing for a more immersive learning experience.

As a complement to hands-on laboratory sessions, digital laboratories are a cost-effective way to ensure students practice their engineering skills [9], and they can be tailored to meet students' individual needs. These tools enable the acquisition of complex knowledge and provide opportunities for personalized learning, experimentation, and collaboration [10]. Multisim® is a widely recognized software tool that combines simulation capabilities with an interactive schematic environment, allowing users to visualize and analyze the behavior of electronic circuits. Previous studies have demonstrated the benefits of Multisim® based courses, including improvements in teaching methods and emphasizing the integration of such tools into the educational process [11]. The benefits provided at the University of Almeria (UAL) for all electronics courses are commendable. By granting Multisim access to its students, direct experience with circuit design, analysis, and simulation is guaranteed.



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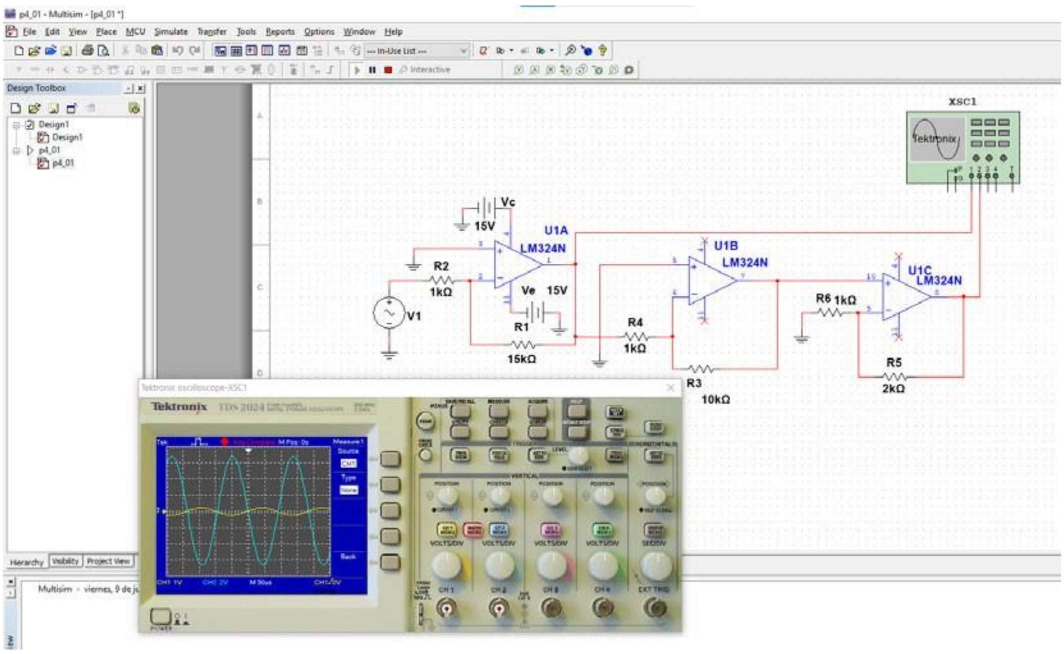

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Figure 1. Different software for electronics. (a) Simulator; (b) Digital laboratory.

Nowadays, digital laboratories have become a familiar and versatile tool in engineering education, continually adapting to new perspectives and possibilities offered by advancements in communications technology. They provide numerous advantages and opportunities for students. Here are some key points to consider:

- Accessibility and convenience: Digital laboratories allow students to access laboratory resources and perform experiments at their convenience. Students can access the laboratory anytime, anywhere, allowing them to learn and engage with the material at their own pace.

- Independent learning: Students can conduct experiments, obtain measurements, and analyze data without the teacher's assistance. This fosters self-directed learning and encourages students to actively explore and apply their knowledge.
- Remote collaboration: Students can interact and share data and results with their peers through online platforms and tools. They can perform experiments online, discuss findings, and learn from one another. This collaborative approach promotes teamwork and communication skills.
- Customization and personalization: Instructors can create tailored experiments, simulations, and scenarios that align with the curriculum and address the specific requirements of each student, tailored to her needs and learning objectives.
- Technological proficiency: Students gain practical experience utilizing technology for scientific inquiry, data analysis, and problem-solving by engaging with intelligent devices and digital platforms. These skills are crucial for future engineers and professionals in an increasingly digital world.

Assessing the effectiveness of introducing a digital laboratory in the practices of the Basic Electronics subject is a valuable research endeavor. Basic Electronics is a compulsory subject in the Industrial Engineering degree of UAL. The knowledge of the subject is relevant and applicable to specific engineering disciplines, so it is taught across four specialties: Industrial Electronics Engineering, Electrical Engineering, Industrial Chemical Engineering, and Mechanical Engineering.

The first analysis was made in the last edition of ICERI2022 [12]. In this article, we aim to determine the impact of changes in the teaching methodology of practical sessions by analyzing one more year of academic results. This evaluation will provide evidence to support the refinement and enhancement of the teaching methodology, leading to continuous improvement in acquiring knowledge and skills among students.

2 METHODOLOGY

There has been a notable evolution in teaching methodology in the Basic Electronics course, a compulsory subject for Industrial Engineering students at the University of Almeria (UAL).

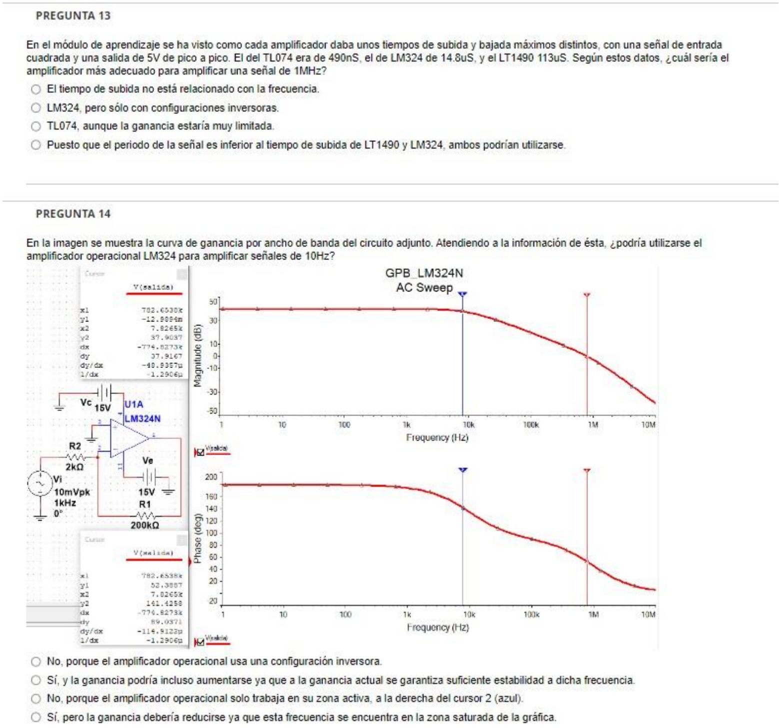
Before the 2019-2020 academic year, the practical component of the course required students to assemble circuits during laboratory sessions. This hands-on approach facilitated learning through experience in circuit construction and analysis. Students collected data, performed measurements, and prepared a detailed report, including circuit assembly details, measurements, and data analysis. Simulators were used as supplementary tools, enabling students to validate their findings.

However, a notable change was implemented in the 2019-2020 academic year; Multisim® was introduced as the primary tool for practices. Its implementation was supported by the Blackboard® e-learning platform, a virtual environment where students could access learning modules containing summaries of key concepts. Additionally, self-assessment tests were introduced on the platform. As depicted in Figure 2a, the test allowed students to gauge their understanding of the material and assess their progress, following the flipped classroom model [13]. It served as a means of self-evaluation and allowed students to identify areas where they needed to focus or review further., allowing students to gauge their understanding and receive instant feedback. Students could attempt these tests repeatedly until successful.

The laboratory sessions followed the self-assessment tests. Students were given the circuit to be designed, analyzed, and built, and the design parameters the circuit must meet. The e-learning platform provided individualized circuits and parameters to each student group to discourage copying and foster original thinking and understanding (Figure 2b). Students analyzed the circuit in the digital laboratory to meet the design parameters and then built it in the laboratory, contrasting both.

This course implementation coincides with the outbreak of the global COVID-19 pandemic, leading to the closure of physical laboratories. Only two face-to-face sessions were conducted before the entire course transitioned online. The digitally based aspect of the course proved to be a fitting seed for this task; students analyzed the circuit in the digital laboratory to meet the design parameters and then submitted screenshots through the e-learning platform as evidence of their work.

Due to the ongoing pandemic, this methodology, in its fully digital aspect, continued into the 2020-2021 academic year. However, in the 2021-2022 academic year, the course returned to its original hybrid model by integrating virtual teachings and physical components. This approach was carried forward into the 2022-2023 academic year. The circumstances around this methodology's implementation produce an interesting sample: one year under the classic, hands-on approach with report-based evaluations, two years under a completely virtual system, and another two with the hybrid approach.



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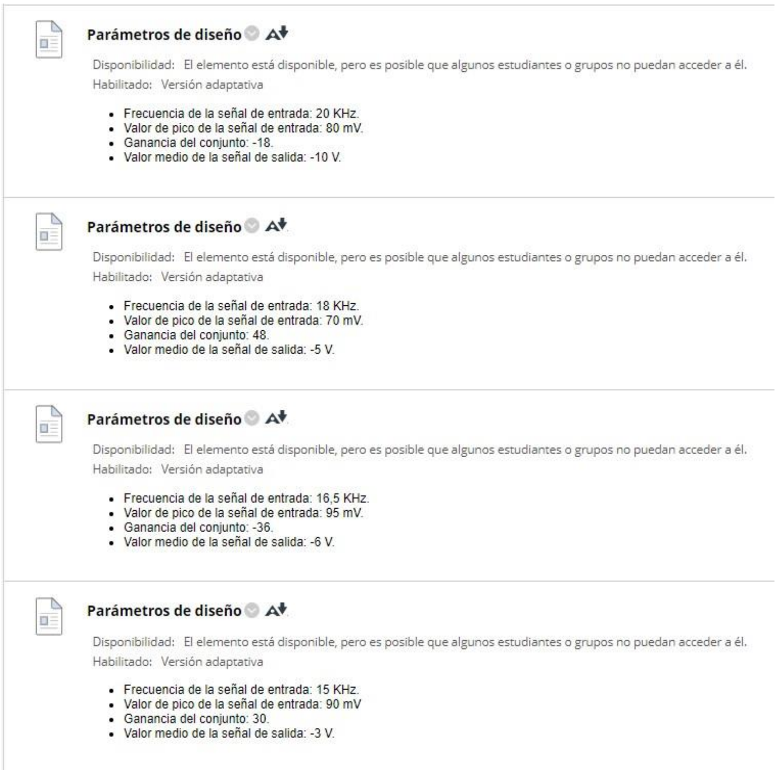

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Figure 2. E-learning platform. (a)Example of a self-assessment test; (b) Customized design parameters for each group of students.

3 RESULTS AND DISCUSSION

To analyze the correlation between the improvements in theory and practices, both have been depicted in Figure 3 and Figure 4. A correlation can be observed between the pass rate in practices and theory, with the rate of passing students consistently higher in practices compared to theory. In years of face-to-face teaching, the theory pass rates remain consistent regardless of the approach used for the practices, except for the last academic year, when there was a noticeable increase in the number of students passing the theory component.

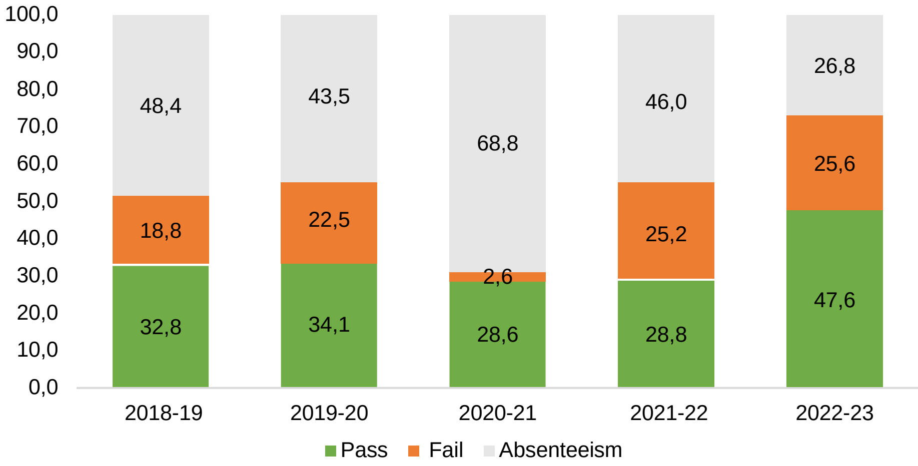

Figure 3. Academic results of theory (in percentage) in the last five years.

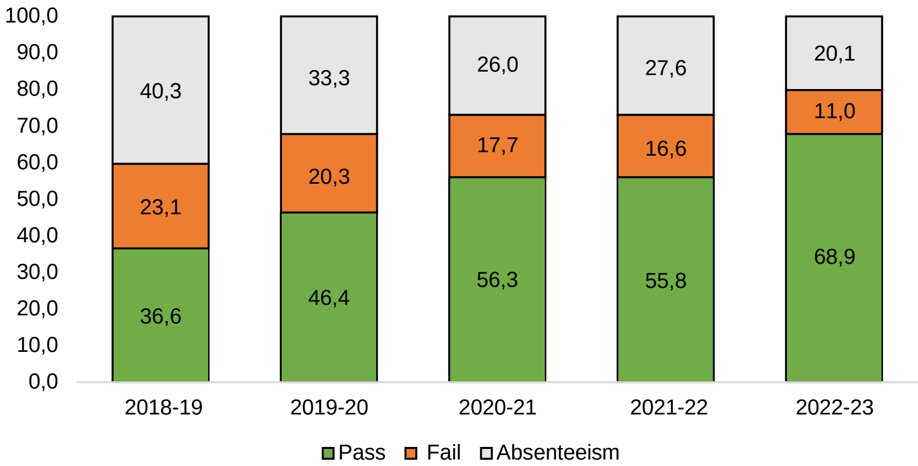

Figure 4. Academic results of practices (in percentage) in the last five years.

In contrast, there is no correlation between the failure rates in practices and theory. Specifically, in the 2019-20, 2021-22, and 2022-23 academic years, there was a higher failure rate in theory than in practices, with a 2.2%, 8.6%, and 14.6% difference, respectively, while in 2018-19 and 2020-21 academic years, there were more failing students in practices than in theory, with a 4.3% and 15.1% respectively.

The absenteeism rate is consistently lower in practices compared to theory. However, higher absenteeism rates are evident in years with online teaching, with a 42.7% higher absenteeism rate in theory than practices in 2020-2021. 2022-2023 has been the year with the lowest level of absenteeism in the past five years, with 26.8% in theory and 20.1% in practices. This suggests that face-to-face learning is less prone to absenteeism due to socializing with classmates and teachers [14]. Reasons for absenteeism under the digital methodology can be attributed to the pedagogical (limited content and interactivity, along with teachers' lack of cognitive and social attendance), technological (unreliable connections and a need for better electronic devices), and social challenges (the lack of human interaction between students and teachers, inadequate physical spaces at home for learning, and limited parental support) brought by the pandemic. These challenges lead to potential student dropout rates and decreased student motivation.

One of the notable social aspects highlighted among the students in the 2021-22 academic year is their limited familiarity with each other. These students entered the university without the opportunity to socialize and meet their peers in person, as the previous year was entirely virtual. Consequently, these students face more significant challenges regarding teamwork skills [15]. This was no longer the case in the academic year 2022-23, as the previous year was taught face-to-face. The results demonstrate that students value the opportunity for social interaction and find it beneficial for enhancing their teamwork abilities compared to virtual courses.

It is observed in Figure 4 that the pass rate in practices has improved with the incorporation of the digital laboratory. Although, in the last three years, the values remained constant. Moreover, failure and absenteeism rates have improved following the digital laboratory's implementation. These findings suggest that digital laboratory has been well-received and demanded by students, who also recognize the importance of physical laboratories in face-to-face teaching [16]. This is further supported by the 2022-23 academic year results, where the absenteeism rate has been the lowest, 20.1%. The pass rate has also been the higher, a 68.9%. Over time, both students and faculty have become more accustomed to the hybrid learning model, leading to more effective teaching and learning strategies.

Table 1 presents data from the last five academic years on the success rate of practices and theory (percentage of students who passed compared to those that took the exam). The lowest success rate, in theory, was in the 2021-22 academic year (53.4%), the first year the hybrid methodology was used. Transitioning from one method of instruction to another can be challenging for both students and instructors. The hybrid methodology may have required some time for adjustment. Students and faculty might have struggled initially to adapt to the new mode of instruction. However, in the 2022-23 academic year, this rate increases to 65%, which suggests that instructors and students have become more accustomed to this methodology and adapted strategies to maximize its benefits, leading to improved outcomes. This is also supported by the highest success rate in practices in the 2022-23 academic year (86.3%), the second year with this methodology.

Table 1. Success rate of the past five years.

Academic year	***Methodology***	***Students***	***Success rate theory (%)***	***Success rate practices (%)***
2018-19	Classic	186	63.5	61.3
2019-20	Virtual	138	60.3	69.6
2020-21	Virtual	192	91.7	76.1
2021-22	Hybrid	163	53.4	77.1
2022-23	Hybrid	164	65.0	86.3

Table 2 displays the students’ grades, illustrating a positive reception to the transition from utilizing simulators to adopting a digital laboratory. In the years since the integration of face-to-face teaching with the digital laboratory, there has been an improvement in students' grades for practices, with the most recent academic year witnessing the highest percentage of students achieving an A grade (Excellent and Very Good) at 17.8%. While simulators enable students to evaluate the behavior of electronic circuits, digital laboratories offer additional benefits by incorporating virtual measurement instruments that emulate the ones the students will utilize in the 20 hours of laboratory sessions. This arrangement allows students to engage with the instruments more freely, and experiment without the fear of damaging them, thus facilitating more efficient learning of their functionalities.

The approach to practices by students has undergone a notable change. Before the 2019-20 academic year, students were required to collect data in the laboratory through various measurements and prepare a lengthy report. A common challenge faced by students was that they needed to fully grasp all the concepts during the laboratory session. Students arrive at the face-to-face laboratory session already having conducted the circuit analysis in the virtual laboratory. This reduces students’ uncertainty regarding the correct assembly of their circuits. The digital laboratory experience gives them a better understanding of the circuit behavior, allowing them to anticipate the outcomes before the physical measurements occur in the laboratory.

Table 2. Percentage of students that achieved each grade.

Grades	*2018-19 (%)*	*2019-20 (%)*	*2020-21 (%)*	*2021-22 (%)*	*2022-23 (%)*
A+ (10)	0.0	1.5	0.0	3.2	6.5
A (9-9.99)	0.0	6.0	5.2	10.8	12.3
B (7-8.99)	1.6	21.0	34.4	27.0	31.7
C (5-6.99)	34.9	17.4	16.7	15.3	19.5
F (0-4.99)	23.1	20.3	17.7	16.6	11.0
Absent	40.3	33.3	26.0	27.6	20.1

4 CONCLUSIONS

Adaptations in higher education have extensively led to a paradigm incorporating digital technology, and this study focuses on the impact of these changes on Basic Electronics practices.

While digital laboratories have shown to be effective in aiding professional skills development, they cannot replace traditional laboratories and work better as a supportive tool. The introduction of digital laboratories led to improved pass rates among students, but this did not consistently correlate with better performance in theoretical aspects. Moreover, years that relied heavily on online teaching showed higher absenteeism rates due to various technological, pedagogical, and social challenges.

Interestingly, implementing digital laboratories led to higher pass rates and improved grades overall, underscoring the potential of digital tools to enhance student performance. The most promising results were observed in academic years when a hybrid model combining digital and face-to-face teaching was used. This suggests that a balanced approach is vital, capitalizing on the strengths of both digital and traditional teaching methodologies. This is so, especially in engineering education, which requires hands-on skills. This balanced approach prepares students more effectively for the dynamic requirements of the professional world. The study advocates for continued analysis of academic results in the future to help fine-tune the integration of digital and traditional teaching methodologies in engineering education for optimal outcomes.

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