Online-Journals.org

iJEP International Journal of Engineering Pedagogy

iJEP | eISSN: 2192-4880 | Vol. 15 No. 2 (2025) | OPEN ACCESS

https://doi.org/10.3991/ijep.v15i2.51739

PAPER

Enhancing Electronics Courses Education: Active Learning Strategies for Undergraduate Engineering Students

Falah Awwad(✉)

United Arab Emirates
University, Al Ain,
United Arab Emirates

f_awwad@uaeu.ac.ae

ABSTRACT

This study provides insights into the effectiveness of active learning strategies in enhancing student outcomes in undergraduate electronics engineering education. The findings demonstrate the significant impact of these strategies on student engagement, practical skills, and overall course performance. While traditional lecture-based teaching methods have long been used, evidence suggests they may not effectively engage students or foster deep learning. This study integrates active learning strategies, such as project-based learning (PBL), simulation software, and flipped classroom techniques, to address these challenges. The study's relevance is highlighted by the rapid advancements in electronics engineering and the demand for engineers proficient in collaboration and problem-solving. It aims to answer: (1) How do active learning strategies impact student engagement and learning outcomes? (2) How do traditional teaching methods compare to active learning in student performance? A quasi-experimental design compared traditional teaching (control group) with active learning strategies (experimental group) over one semester. Results showed a 15% increase in overall course performance, a 20% enhancement in practical skills, a 14% rise in student engagement, and an 8% improvement in exam scores in the experimental group, supporting the broader adoption of active learning in electronics education.

KEYWORDS

active learning strategies, electronics education, flipped classroom techniques, project-based learning (PBL), undergraduate engineering education

1 INTRODUCTION

Electronics is a fundamental subject in electrical and electronic engineering, and it is essential for students to gain a strong understanding of the principles and applications of electronics. However, teaching electronics to undergraduate electrical and electronic engineering students can be challenging due to the complexity of

Awwad, F. (2025). Enhancing Electronics Courses Education: Active Learning Strategies for Undergraduate Engineering Students. *International Journal of Engineering Pedagogy (iJEP)*, 15(2), pp. 42–73. https://doi.org/10.3991/ijep.v15i2.51739

Article submitted 2024-08-14. Revision uploaded 2024-12-07. Final acceptance 2024-12-07.

the subject and the diverse backgrounds of the students. In order to ensure effective learning outcomes, it is important to use appropriate pedagogical methods that are tailored to the needs of the students [1, 2].

This study aims to address two primary objectives: (1) to evaluate the effectiveness of active learning strategies in enhancing student engagement and learning outcomes in undergraduate electronics engineering education, and (2) to compare traditional lecture-based methods with innovative pedagogical approaches such as flipped classrooms and project-based learning (PBL). Based on existing literature and preliminary evidence, we hypothesize that active learning strategies will significantly improve student engagement, practical skills, and overall academic performance compared to traditional methods.

The purpose of this manuscript is to provide an overview of effective methods for teaching electronics to undergraduate electrical engineering (EE) students. It discusses various pedagogical approaches, including traditional lecture-based teaching [3], active learning strategies [1, 4], problem-based learning [5, 6], PBL [7], the flipped classroom approach, and blended learning. Additionally, the manuscript offers guidance on implementing these approaches in the classroom, including designing a course curriculum, selecting appropriate teaching methods, preparing teaching materials, conducting effective classroom sessions, and evaluating and assessing student learning outcomes. This study specifically evaluates the effectiveness of active learning strategies in the Fundamentals of Microelectronics course, an undergraduate core subject in electronics engineering.

Ultimately, the goal of this manuscript is to provide instructors with a comprehensive guide on how to effectively teach electronics to undergraduate EE engineering students. By using the methods and strategies outlined in this manuscript, instructors can help students gain a strong understanding of electronics and develop the skills needed to succeed in their future careers.

1.1 Educational philosophy and approach

As a teacher, I believe that I have a responsibility not only to transfer knowledge and information to students and evaluate their mastery of course material, but also to inspire them to actively pursue knowledge and to become independent thinkers. This superior learning experience occurs only when students assume personal responsibility for their education. This, in turn, is accomplished by creating a positive learning environment that fosters creativity and excellence, maintains a context of the broad scope of the curriculum, and clarifies what is expected for success.

1.2 Background on teaching electronics to bachelor engineering students

Teaching electronics to bachelor engineering students has been a topic of interest for many years. Previous research has shown that traditional lecture-based teaching may not be the most effective method for teaching electronics to undergraduate students [3, 4]. Instead, active learning strategies, problem-based learning, PBL, flipped classroom approaches, and blended learning approaches have been suggested as alternative methods for teaching electronics to undergraduate students [1, 5–7].

Research in engineering education consistently underscores the effectiveness of active learning strategies, particularly in STEM disciplines. For instance, Freeman et al. [10] demonstrated that active learning significantly enhances student performance across various STEM courses. Similarly, Abeysekera and Dawson [8] reported that flipped classroom approaches improved student engagement and motivation in engineering subjects. These findings align with studies in electronics education, where PBL has been shown to deepen understanding of complex concepts, such as circuit design and system analysis [7]. This study contributes to this growing body of literature by focusing on how these strategies impact undergraduate electronics engineering courses specifically.

Active learning strategies are focused on engaging students in the learning process through activities that encourage critical thinking and problem-solving. This approach has been shown to improve student learning outcomes in the field of electronics [1, 4]. Problem-based learning is another approach that has been used in the teaching of electronics, in which students work on real-world problems and develop solutions based on the principles they have learned [5, 6]. PBL is another effective method for teaching electronics, in which students work on a project that requires them to apply the concepts and principles they have learned to a real-world scenario [7].

The flipped classroom approach and blended learning approach are also effective methods for teaching electronics to undergraduate students. The flipped classroom approach involves students watching pre-recorded lectures or reading materials before attending class, allowing for more in-class time to be spent on interactive activities and problem-solving [8]. Blended learning, on the other hand, combines traditional classroom teaching with online resources and activities, allowing students to learn at their own pace and providing more opportunities for interactive learning [9].

In summary, there are several effective pedagogical approaches that can be used to teach electronics to undergraduate engineering students. By selecting and implementing appropriate teaching methods, instructors can help students develop a strong understanding of electronics and prepare them for successful careers in the field.

1.3 Importance of effective teaching methods

The use of effective teaching methods is critical to ensure that undergraduate engineering students acquire the necessary skills and knowledge to succeed in their future careers. Research has shown that traditional lecture-based teaching methods are not always effective in promoting deep learning and may result in low levels of student engagement and motivation [1, 10]. Therefore, it is essential to use pedagogical methods that encourage active learning, critical thinking, problem-solving, and collaboration [11, 12].

Pedagogical methods, such as PBL and flipped classrooms, serve as the overarching frameworks designed by instructors to foster active engagement and create structured learning environments. These methods outline how instruction is delivered and how classroom activities are organized. In contrast, learning strategies refer to the specific techniques or approaches that student adopt within these frameworks to enhance their learning experience. For example, in a flipped classroom, students may use strategies such as pre-class video annotations or peer-led discussions to solidify their understanding. Similarly, in PBL, students might employ collaborative brainstorming or iterative problem-solving as learning strategies to achieve project objectives.

Effective teaching methods have been shown to improve student learning outcomes and retention rates in engineering education. For example, problem-based learning has been found to enhance student engagement, motivation, and learning outcomes compared to traditional lecture-based methods [5, 6]. PBL has also been found to be an effective method for teaching engineering subjects, as it allows students to apply theoretical concepts to real-world problems and situations [6, 7].

Flipped classrooms have been widely adopted in engineering education due to their ability to transform passive learning environments into interactive, student-centered experiences. For example, Chen et al. [21] found that flipped classrooms in engineering led to higher student engagement and better application of theoretical knowledge. Similarly, PBL has been shown to improve practical skills and teamwork, as observed in studies by Kolmos et al. [6]. While these strategies have demonstrated success in engineering education broadly, their application in electronics education, particularly in integrating hands-on learning with theoretical concepts, remains underexplored. This study builds on prior research by evaluating their combined impact in the context of undergraduate electronics engineering.

Active learning strategies, such as flipped classroom and blended learning approaches, have also been shown to be effective in promoting student engagement and improving learning outcomes in engineering education [8, 9]. These strategies encourage students to take an active role in their learning by participating in activities that promote critical thinking, problem-solving, and collaboration. Moreover, these methods allow students to learn at their own pace and provide more opportunities for interactive learning.

In summary, the use of effective teaching methods is critical in promoting deep learning, engagement, and motivation among undergraduate engineering students. By selecting and implementing appropriate pedagogical methods, instructors can help students develop the necessary skills and knowledge to succeed in their future careers.

1.4 Purpose of the manuscript

The purpose of this study is to investigate the efficacy of active learning strategies, such as problem-based learning, PBL, flipped classrooms, and blended learning, in enhancing student outcomes in undergraduate electronics education. By employing a quasi-experimental design in the Fundamentals of Microelectronics course, the study evaluates the impact of these strategies on student engagement, practical skills, and academic performance compared to traditional teaching methods.

This study aims to provide instructors with evidence-based pedagogical methods that have demonstrated effectiveness in promoting deep learning and motivation among students. Practical guidance is offered on implementing these approaches, including designing course curricula, selecting teaching methods, preparing materials, conducting sessions, and evaluating learning outcomes.

Ultimately, the manuscript seeks to contribute to the growing body of research advocating for innovative teaching methods in engineering education. It provides actionable insights and strategies to help educators enhance student understanding of complex electronics concepts and prepare them for success in their future careers.

2 OVERVIEW OF ELECTRONICS EDUCATION

2.1 Comparison of pedagogical approaches

In reviewing the existing literature on teaching electronics to undergraduate students, it is evident that traditional lecture-based methods dominate the educational landscape. However, studies have shown that active learning strategies, such as those proposed in this paper, can lead to enhanced student engagement and deeper understanding of complex concepts [1,10]. For instance, problem-based learning has been shown to foster critical thinking and problem-solving skills more effectively than conventional teaching methods [6]. Similarly, the flipped classroom approach has been associated with increased student motivation and academic performance [8]. Despite these advancements, there remains a gap in the widespread adoption and assessment of such innovative strategies in the context of electronics education.

To illustrate the differences between these pedagogical approaches, Table 1 compares their key characteristics. The content is based on established literature, including traditional lecture-based teaching [3, 4, 11], problem-based learning [5, 6, 20], flipped classrooms [8, 21, 23], PBL [7, 17, 18], and blended learning [9, 26]. This table highlights the contrast between traditional and active learning strategies in terms of teaching methods, student engagement, skills emphasis, adaptability to new technologies, and alignment with learning objectives in electronics education.

Table 1. Comparison of pedagogical approaches in electronics education

Approach	Teaching Method	Student Engagement	Skills Emphasis	Adaptability to New Technologies	Learning Objectives
Traditional Lecture	Direct instruction, passive learning	Low	Theoretical knowledge	Limited	Build foundational understanding of core concepts.
Problem-Based Learning	Student-centered, active problem solving	High	Critical thinking, problem-solving	Moderate	Develop problem-solving abilities and apply theoretical knowledge to real-world challenges.
Flipped Classroom	Pre-class online materials, in-class activities	Moderate	Self-learning, application	High	Foster active in-class participation, improve pre-class preparation, and enhance application skills.
Project-Based Learning	Real-world projects, teamwork	High	Technical skills, teamwork, communication	High	Encourage collaboration, creativity, and hands-on technical skills through real-world applications.

2.2 Challenges in electrical and computer engineering education

Many students who initially select Electrical and Computer Engineering are destined for failure for two reasons: they lack a mastery of fundamentals in physics and mathematics, and they don't achieve a broad understanding of elementary electronics. My approach to teaching involves emphasizing fundamentals from the start. As advanced topics are introduced, their relevance to basic electronics is always articulated. Moreover, electrical and computer engineering courses must begin with a cursory overview of the subject. This big picture is what allows students to organize thoughts and concepts and to organize their study.

2.3 Challenges in teaching electronics

Teaching electronics to undergraduate engineering students can be challenging for instructors due to the abstract and complex nature of the subject matter. Electronics involves understanding the behavior and characteristics of various electronic components, such as transistors, diodes, and integrated circuits, as well as the principles of circuit analysis and design. Moreover, electronics is a rapidly evolving field, with new technologies and applications emerging frequently, making it challenging for instructors to keep up with the latest developments [13].

Another challenge in teaching electronics is ensuring that students have the necessary background knowledge and skills to understand and engage with the subject matter. Electronics builds on foundational concepts in physics and mathematics, and students who lack proficiency in these areas may struggle to grasp electronics concepts [13].

Traditional teaching methods encompass a range of approaches that have historically been used in engineering education, including direct instruction, textbook-driven lectures, and chalk-and-talk methods. While these methods focus on delivering content efficiently to large groups, they may not provide sufficient opportunities for active student engagement, interaction, or practical application. The term "traditional lecture-based teaching methods," often used interchangeably with "didactic methods," refers specifically to content delivery where instructors present material in a largely unidirectional format, and students passively receive information. Although efficient for covering theoretical concepts, these approaches may not be effective in promoting deep learning, as they typically lack interactive elements such as discussions or hands-on activities [1].

In contrast, teaching methods such as active learning, PBL, and flipped classrooms emphasize student engagement and collaboration, encouraging deeper understanding and application of knowledge. These methods are built on the principle that learning is most effective when students actively participate in the learning process.

To address these challenges, many universities are adopting innovative pedagogical approaches to electronics education, such as PBL, flipped classrooms, and blended learning [8, 9]. These pedagogical methods provide frameworks for integrating learning strategies, such as collaborative problem-solving, peer discussions, and simulation exercises. These approaches offer students opportunities to actively engage with the material, collaborate with peers, and apply their knowledge to real-world problems, promoting deep learning and enhancing student motivation and engagement.

In summary, teaching electronics to undergraduate engineering students presents several challenges related to the abstract and complex nature of the subject matter, the rapid pace of technological developments, and the need to ensure that students have the necessary background knowledge and skills. While traditional lecture-based teaching methods can provide foundational theoretical knowledge, they often fall short in fostering engagement, critical thinking, and problem-solving skills. Innovative pedagogical approaches can address these shortcomings by creating interactive and student-centered learning environments that promote deep learning and engagement.

2.4 The significance of semiconductor knowledge

In our daily lives, we rely on electronic (VLSI-based, optoelectronic, and photonic) equipment, such as computers, radios, phones, scanners, and copiers. At the heart of these devices are semiconductors. As we transition from the electronics age to the Ultra-Large-Scale Integration (ULSI) age, it is essential for graduating science or engineering majors to be equipped with a solid understanding of semiconductor concepts and devices. Semiconductors, such as silicon and germanium, possess electrical properties that lie between those of conductors and insulators. Their unique behavior forms the foundation of modern electronics.

To effectively teach semiconductor concepts, a pedagogical strategy that balances theoretical knowledge with practical applications is critical. Traditional lecture-based methods, while useful for introducing fundamental principles such as energy bands and charge carriers, must be supplemented with active learning strategies to engage students and deepen their understanding. For instance, problem-based learning can be employed to explore doping effects or the design of P-N junctions, where students analyze real-world scenarios and develop solutions.

The following semiconductor-based topics are foundational in early basic electronics courses: crystal structure, energy bands, charge carriers, Fermi level, carrier lifetime, mobility, optical properties of semiconductors, doping, P-N junctions, diodes, semiconductor detectors, and transistors. To reinforce these concepts, hands-on laboratory sessions and simulation tools, such as SPICE or MATLAB, can allow students to visualize and manipulate semiconductor behaviors in controlled environments. This combination helps bridge the gap between theory and application.

Advanced analog and digital VLSI undergraduate and graduate courses further build on these foundations by integrating these semiconductor concepts into practical design challenges. Pedagogical strategies such as PBL can be particularly effective at this level, where students collaborate on designing semiconductor devices or circuits. For example, students might design a MOSFET amplifier, considering factors such as mobility, carrier lifetime, and energy efficiency.

In summary, while a comprehensive understanding of semiconductor knowledge is crucial for modern engineers, its effective teaching requires a multifaceted approach. By integrating active learning strategies, practical simulations, and PBL, instructors can ensure students develop not only theoretical expertise but also the critical problem-solving and design skills necessary for success in the rapidly evolving field of electronics.

2.5 Current state of electronics education

Electronics is a core subject in undergraduate engineering programs, and it plays a critical role in shaping the technological landscape of modern society. However, there are concerns that the traditional lecture-based teaching methods used in many electronics courses may not be effective in promoting deep learning and may lead to low levels of student engagement and motivation [1, 10].

Moreover, there is a growing demand for engineers who possess not only technical skills but also the ability to work in multidisciplinary teams, communicate effectively, and solve complex problems [14]. However, traditional lecture-based teaching methods may not adequately prepare students with these skills.

To address these concerns, many universities are adopting innovative pedagogical approaches to electronics education. For example, some institutions are using PBL to teach electronics concepts, where students work in teams to solve real-world problems [6, 7]. Others are implementing blended learning approaches, where students learn through a combination of online and face-to-face instruction [8, 9].

Despite these efforts, there are still challenges to overcome in electronics education. For example, there is a need to ensure that these innovative pedagogical approaches are effective and accessible to all students. Moreover, there is a need to develop and implement effective assessment strategies to measure student learning outcomes and ensure that students are developing the necessary skills and knowledge to succeed in their future careers.

In summary, there are ongoing efforts to improve electronics education in undergraduate engineering programs. These efforts involve adopting innovative pedagogical approaches and developing effective assessment strategies. However, there is still a need to address challenges and ensure that all students have access to effective and engaging electronics education.

2.6 Trends in electronics education

The field of electronics is constantly evolving, and education in this field must keep up with the latest trends and developments. One major trend in electronics education is the increasing use of technology to enhance the learning experience. This includes the use of simulation software, online tools and resources, and digital textbooks [15]. The use of technology can help to make abstract concepts more tangible and can allow students to explore complex systems and phenomena in a virtual environment [16].

Another trend in electronics education is the focus on interdisciplinary learning. Electronics intersects with many other fields, including physics, computer science, and materials science, among others [17]. As such, electronics education is increasingly incorporating interdisciplinary perspectives, allowing students to see the connections between electronics and other fields and to apply their knowledge in a broader context.

Project-based learning is another trend in electronics education. This approach involves students working on real-world projects that require them to apply their knowledge and skills to solve practical problems [18]. PBL can be particularly effective in electronics education, as it allows students to see the real-world applications of the concepts they are learning and to develop skills in teamwork, communication, and project management.

Finally, there is a growing trend towards the use of active learning strategies in electronics education. Active learning involves engaging students in activities that require them to apply their knowledge and skills, such as group work, problem-solving activities, and case studies [10]. Active learning can help to promote deeper learning, enhance student engagement and motivation, and develop critical thinking and problem-solving skills.

In summary, trends in electronics education include the increasing use of technology, interdisciplinary learning, PBL, and active learning strategies. These trends reflect a growing recognition of the importance of engaging students in meaningful, practical learning experiences that prepare them for success in the rapidly evolving field of electronics.

3 PEDAGOGICAL APPROACHES

3.1 Traditional lecture-based teaching

Traditional lecture-based teaching has been the primary mode of instruction in higher education for many years. This method involves an instructor presenting information to students in a structured lecture format, often accompanied by slides or other visual aids. While this approach allows for efficient delivery of large amounts of content, it is typically characterized by a one-way flow of information from the instructor to the students, with limited opportunities for interaction or active engagement [1].

Research has shown that traditional lecture-based teaching is less effective than more interactive and student-centered pedagogical approaches, particularly for complex subjects such as engineering [1, 11]. This approach is often criticized for its lack of engagement, limited opportunities for feedback and interaction, and its focus on passive learning [10]. These limitations make it challenging for students to develop critical thinking, problem-solving, and collaborative skills, which are essential for success in modern engineering fields.

In this paper, we take the position that while traditional lecture-based teaching has value in establishing foundational theoretical concepts and providing a broad overview of a subject, it is insufficient on its own to meet the demands of contemporary engineering education. Effective teaching strategies must emphasize active engagement, interaction, and the application of knowledge to real-world scenarios. This can be achieved by integrating traditional lectures with complementary pedagogical approaches, such as flipped classrooms, PBL, and problem-based learning.

For example, traditional lectures can be enhanced through active learning strategies, such as incorporating concept checks, peer discussions, or collaborative problem-solving exercises during class sessions. These methods align with the broader pedagogical framework outlined in this paper, which emphasizes the importance of fostering student engagement, practical skills, and higher-order cognitive abilities.

By positioning traditional methods as one component of a broader pedagogical strategy, this paper advocates for a balanced approach that leverages the strengths of lectures while addressing their limitations through the integration of active and interactive teaching techniques. This hybrid approach provides a pathway for instructors to meet the diverse needs of students in engineering education, promoting both foundational knowledge and the skills required for deeper learning and practical application.

3.2 Active learning strategies

Active learning strategies involve students in the learning process by engaging them in activities that require higher-order thinking, problem-solving, and collaboration. Such strategies aim to promote deep learning, critical thinking, and long-term retention of knowledge. Examples of active learning strategies include problem-based learning, PBL, flipped classrooms, peer instruction, inquiry-based learning, and collaborative learning [1, 10].

Active learning has been shown to improve student learning outcomes and engagement in a variety of disciplines, including science, technology, engineering, and mathematics (STEM) fields [1, 10]. In engineering education, active learning strategies have been found to be particularly effective in promoting student engagement, motivation, and deeper learning [3].

One study compared the effectiveness of traditional lecture-based teaching with active learning in large engineering classrooms and found that active learning led to significant improvements in student learning outcomes, particularly for female and underrepresented minority students [3]. Another study found that incorporating active learning strategies, such as PBL and simulation-based learning, improved student engagement and learning outcomes in an undergraduate electronics engineering course [16].

3.3 Problem-based learning

Problem-based learning is an approach that focuses on students solving real-world problems, often in groups, as a means of learning content and developing skills. Problem-based learning is student-centered and promotes critical thinking, problem-solving, and collaboration. Problem-based learning has been widely used in medical education and has been found to be effective in promoting deep learning, retention of information, and transfer of learning to clinical practice [19]. It has also been applied in engineering education, where it has been found to be effective in promoting student engagement and enhancing their understanding of complex engineering concepts [5, 6].

In problem-based learning, students are presented with a problem scenario and are asked to identify what they already know, what they need to know, and how they can find the information they need. Students work collaboratively to research the problem, propose solutions, and evaluate their effectiveness. The teacher takes on a facilitative role, providing guidance and feedback throughout the process.

3.4 Project-based learning

Project-based learning is a teaching approach that emphasizes student-centered learning through the completion of a project that addresses a real-world problem or question. Students work in groups to identify a problem or question, conduct research, and develop a solution or answer to the problem or question. PBL has been shown to be an effective approach for teaching a variety of subjects, including engineering [5, 7, 20].

Project-based learning is thought to be effective because it promotes student engagement, motivation, and deeper learning [6]. Additionally, PBL encourages the development of higher-order thinking skills, such as problem-solving, critical thinking, and creativity [6, 18].

One study found that students in an electronics course who learned through a PBL approach demonstrated better learning outcomes compared to those who learned through a traditional lecture-based approach [7]. Another study found that PBL was an effective approach for teaching interdisciplinary mechatronics and electronics courses [17].

3.5 Flipped classroom approach

In a flipped classroom approach, students are provided with pre-recorded video lectures, readings, and other resources to study outside of class, while in-class time is dedicated to interactive activities such as discussions, problem-solving, and projects. This approach aims to shift the focus from teacher-centered learning to student-centered learning and can enhance student engagement and critical thinking skills.

Research has shown the effectiveness of the flipped classroom approach in improving students' academic performance, motivation, and satisfaction in various disciplines, including engineering [8, 21–23]. In a study by Chen et al. [21], the authors compared the learning outcomes of a flipped classroom and a traditional lecture-based classroom for an introductory engineering course and found that the flipped classroom approach resulted in significantly better learning outcomes and higher student engagement.

However, the implementation of flipped classroom approach also requires careful planning and preparation, as students may face challenges with self-directed learning and need support to effectively engage in in-class activities [24, 25].

3.6 Blended learning approach

Blended learning is a pedagogical approach that combines traditional face-to-face classroom instruction with online learning activities, allowing students to have more control over their learning and providing greater flexibility in terms of time and location. The online component can include a variety of resources, such as videos, simulations, interactive activities, discussion forums, and assessments, which can be accessed through a learning management system (LMS) or other online platforms. In a blended learning environment, the instructor serves as a facilitator and provides guidance and feedback to students as they work through the course materials.

Blended learning has been shown to have a positive impact on student engagement, satisfaction, and learning outcomes in various disciplines and educational settings [9]. Moreover, it can help to address some of the challenges faced by traditional classroom instruction, such as limited time, space, and resources, and the need to accommodate diverse learning styles and preferences [26].

Recent studies have explored different approaches to designing and implementing blended learning in engineering education, such as integrating online simulations and virtual laboratories into the curriculum [16], combining problem-based learning with online discussions and peer review [5], and using mobile technologies to support collaborative and interactive learning [17].

4 INNOVATIVE TEACHING CASE STUDIES FOR EE UNDERGRADUATES

In transitioning from theoretical frameworks to the practical application of teaching methodologies, it becomes imperative to examine real-world examples that exemplify the effectiveness of these approaches in the EE undergraduate curriculum. This section aims to bridge this gap by presenting a series of case studies that highlight innovative teaching strategies in action. From interactive lab work that deepens students' practical understanding to the integration of simulation software that brings complex concepts to life, these case studies serve as a testament to the transformative potential of active learning. By exploring collaborative projects and industry partnerships, we further illustrate how academia and the professional world can converge to enrich the educational experience, preparing students for the challenges and opportunities of the electronics field.

4.1 Interactive lab work

In the evolving landscape of EE education, interactive lab work emerges as a crucial strategy for linking theoretical knowledge with practical application. This case study explores the extensive implementation of hands-on lab sessions for EE undergraduates. Students engaged in a wide range of projects, from basic circuit design on breadboards to advanced simulations with SPICE and MATLAB. These collaborative projects foster teamwork and problem-solving skills, reflecting industry practices. Notably, we observed a 25% increase in student engagement, alongside significant improvements in test scores and practical skills. Student feedback underscored an increased confidence in addressing real-world electronics challenges, highlighting the critical role of practical experience in the EE curriculum. Such interactive lab works not only bolsters learning outcomes but also equips students for the complexities of the electronics industry. Referencing the work of Froyd and Ohland in [27], the integration of lab sessions into engineering curricula and its subsequent impact on student engagement and learning were discussed. Furthermore, the authors of [28] provided insights into active learning strategies, such as project-based and problem-based learning, which closely align with our implementation of interactive lab work.

4.2 Simulation software integration

In the evolving landscape of EE education, the integration of simulation software has become a pivotal strategy for seamlessly connecting theoretical concepts with practical applications. This case study elaborates on the strategic incorporation of simulation tools, notably SPICE and MATLAB, into the educational curriculum. These tools provide students with immersive, hands-on experiences in designing and analyzing electronic circuits, circumventing the need for physical components.

The implementation strategy involved the development of a comprehensive suite of projects enabling students to simulate and solve real-world electronic challenges. These ranged from straightforward circuit analysis to the intricacies of complex system behaviors. By forging collaborations with industry partners, the curriculum remained abreast of current technological trends and challenges, equipping students with skills that are both relevant and current.

Significant outcomes were observed from this educational approach. Student engagement soared, evidenced by a marked improvement in both the depth of understanding and the capacity to apply theoretical knowledge to practical situations. Qualitative feedback from participants revealed a substantial boost in confidence when addressing complex electronic issues, a direct consequence of the experiential learning facilitated by simulation. The findings of Alam [29] resonate with these observations, illustrating the profound impact of modeling and computer simulation on enhancing both learning outcomes and student engagement. This alignment with the aims of the present case study is unmistakable.

Highlighting the indispensable role of simulation software in contemporary EE education, this case study advocates for a thoughtful integration of simulation-based projects into the curriculum. Such integration should be closely aligned with educational objectives and industry expectations. Ongoing evaluation and refinement, informed by student feedback and technological progress, are essential for optimizing the learning experience and adequately preparing students for the multifaceted challenges of the electronics industry.

4.3 Collaborative design projects

In the dynamic field of EE education, the incorporation of collaborative design projects represents a forward-thinking approach aimed at enhancing the practical and theoretical understanding of students. This case study examines the implementation of collaborative projects that integrate theoretical concepts with hands-on experience, preparing students for real-world engineering challenges.

The primary objective of integrating collaborative design projects into the EE curriculum is to foster a comprehensive understanding of EE principles through teamwork, problem-solving, and real-world applications. By engaging in projects that require collaboration, students not only deepen their technical knowledge but also develop essential soft skills such as communication, leadership, and project management.

The implementation involved the introduction of team-based projects where students were tasked with designing, developing, and testing electronic systems. Projects ranged from renewable energy systems to smart home technologies, incorporating the use of simulation software such as MATLAB and Computer-Aided Design (CAD) tools for design and analysis. Industry partnerships were established to provide students with insights into current engineering practices and standards, as well as to offer real-world problems for students to solve.

The collaborative project approach led to a notable increase in student engagement and motivation. Students demonstrated a deeper understanding of EE concepts, as evidenced by a 30% improvement in project assessment scores compared to traditional solo projects. Qualitative feedback indicated that students valued the opportunity to work on real-world problems, which increased their confidence and preparedness for entering the workforce. Furthermore, collaboration with industry partners allowed students to gain insights into emerging technologies and industry expectations.

This case study highlights the significant benefits of integrating collaborative design projects into the EE curriculum. The hands-on, team-based approach not only enhances technical skills but also prepares students for the collaborative nature of the engineering profession. Educators considering this approach should ensure projects are aligned with course objectives and reflect current industry challenges. Regular feedback from industry partners and students can guide the continuous improvement of project relevance and educational impact.

4.4 Industry partnership for real-world exposure

In the rapidly advancing field of EE, fostering a strong connection between academic learning and industry practices has become increasingly vital. This case study delves into the strategic integration of industry partnerships within the EE curriculum to provide students with real-world exposure and hands-on experience, thereby bridging the gap between theoretical knowledge and practical application.

Industry partnerships play a pivotal role in bridging the gap between theoretical learning and practical applications in engineering education. Collaborations with industry expose students to real-world challenges, enhance their technical and professional skills, and prepare them for the demands of the workforce [14, 58]. For example, industry-oriented teaching strategies have been shown to improve student engagement and learning outcomes by integrating practical scenarios into the curriculum [58]. Similarly, PBL in mechatronics has demonstrated the benefits of incorporating industry-related projects to provide hands-on experience [17]. Engaging with industry also aligns with the broader goals of community involvement and prepares students for the evolving landscape of engineering [73].

The main objective of embedding industry partnerships in EE education is to acquaint students with the current technological and engineering challenges faced by professionals in the field. This initiative aims to enhance students' practical skills, adaptability, and readiness for the workforce by involving them in projects that reflect real-world problems and solutions.

The implementation process entailed forming alliances with leading engineering firms and technology companies to develop projects that are directly relevant to the industry's needs. Students engaged in projects involving the latest EE technologies, such as renewable energy systems, IoT (Internet of Things) applications, and advanced semiconductor devices, using tools such as CAD for circuit design and simulation software for system analysis.

These partnerships also facilitated internships, guest lectures, and workshops led by industry experts, providing students with valuable insights into professional practices, emerging technologies, and market trends.

The introduction of industry partnership projects resulted in a significant uplift in student engagement and enthusiasm for learning. Quantitatively, there was a 40% increase in the number of students pursuing internships and a 35% improvement in job placement rates upon graduation. Qualitatively, student feedback reflected an enhanced understanding of engineering concepts, greater confidence in tackling complex projects, and a profound appreciation for the relevance of their academic studies to real-world applications.

This case study highlights the transformative impact of industry partnerships on EE education, demonstrating that such collaborations are essential for preparing students for successful careers in engineering. For educators seeking to adopt this model, it is recommended to foster relationships with a diverse range of companies to cover various specialties within EE. Continual dialogue with industry partners can help ensure that academic projects remain relevant and aligned with current industry standards and challenges.

5 IMPLEMENTATION STRATEGIES

5.1 Designing a course curriculum

Designing a course curriculum is a critical step in ensuring student learning outcomes are met. The process involves identifying learning objectives, selecting appropriate instructional materials, designing assessments, and developing instructional strategies. The course curriculum should be aligned with the program and institutional learning outcomes and be flexible enough to accommodate student needs and interests.

One approach to course design is the backward design method, where the instructor begins with the desired learning outcomes and works backward to identify the assessments and instructional strategies needed to achieve those outcomes [30]. This approach ensures that the course curriculum is focused on the most important learning outcomes and is designed to achieve those outcomes effectively.

Another important consideration in course design is the selection of appropriate instructional materials. This includes textbooks, articles, multimedia resources, and other materials that can help students achieve the desired learning outcomes. When selecting instructional materials, instructors should consider factors such as the accuracy and relevance of the content, the level of difficulty, and the cultural appropriateness of the material [31].

Assessments are also an important component of course design. Assessments should align with the course learning objectives and should provide opportunities for students to demonstrate their knowledge and skills. Instructors should consider using a variety of assessment methods, including formative and summative assessments, to provide a comprehensive view of student learning [32].

Finally, instructional strategies are essential for effective course delivery. Instructors should consider using a variety of instructional strategies, including lectures, discussions, group work, and hands-on activities, to engage students and facilitate their learning. The selection of instructional strategies should be based on the course learning objectives and the needs and interests of the students [33].

5.2 Selecting appropriate teaching methods

The implementation of effective teaching methods is essential for achieving successful learning outcomes. In selecting appropriate teaching methods, educators need to consider various factors such as the subject matter, the learning objectives, the learning styles of students, and the resources available. According to Chickering and Gamson in [34], effective teaching methods should adhere to seven principles of good practice, including encouraging active learning, providing prompt feedback, emphasizing time on task, communicating high expectations, respecting diverse talents and ways of learning, encouraging cooperation among students, and emphasizing the importance of contact between students and faculty. To implement these principles, educators should follow several strategies.

First, educators should assess the learning needs of their students before implementing teaching methods. This can be done through diagnostic testing, pre-assessment, and feedback from students [35]. Second, educators should be flexible and willing to adapt their teaching methods based on the needs of their students. This could include adjusting the pace of the course, modifying the teaching style, or incorporating new teaching methods [36]. Third, collaboration among educators can be helpful in selecting appropriate teaching methods. This can include sharing ideas, resources, and best practices [37]. Fourth, gathering feedback from students is an important aspect of implementing teaching methods. This can be done through surveys, evaluations, and discussions [1]. Finally, educators should engage in continuous professional development to stay up-to-date with the latest research and practices in teaching methods [34, 38–40].

As education continues to evolve, new teaching methods are constantly being developed and implemented. Therefore, it is essential for educators to stay up-to-date with the latest research and practices in teaching methods. Some of the current trends in teaching methods include gamification, blended learning, and personalized learning [36].

5.3 Preparing teaching materials

Preparing effective teaching materials is essential for promoting successful learning outcomes. Educators need to ensure that their materials are well-organized, up-to-date, and easily accessible to their students. There are several strategies that educators can use to prepare effective teaching materials.

First, educators should consider the learning styles of their students when preparing teaching materials. Different students have different learning styles, and educators need to ensure that their materials are designed to cater to these styles. For example, some students may prefer visual aids such as diagrams and graphs, while others may prefer written materials such as textbooks and handouts [41].

Second, educators should ensure that their materials are up-to-date and accurate. This is particularly important in subjects that are constantly evolving, such as technology and science. Educators should ensure that their materials reflect the most recent research and developments in the field [38].

Third, educators should consider using multimedia materials such as videos, podcasts, and interactive simulations. These materials can help to engage students and promote active learning. Educators should also ensure that their materials are accessible to students with disabilities [24].

Fourth, educators should ensure that their materials are well-organized and easy to navigate. This can include using clear headings, tables of contents, and hyperlinks to help students find the information they need quickly and easily.

Finally, educators should gather feedback from students on their materials. This can be done through surveys, evaluations, and discussions. Feedback can help educators to identify areas where their materials need improvement and make adjustments accordingly [1].

As technology continues to evolve, new tools and platforms for preparing teaching materials are constantly being developed. Educators should stay up-to-date with the latest tools and platforms to ensure that their materials are effective and engaging [40].

5.4 Conducting effective classroom sessions

Conducting effective classroom sessions is crucial for achieving successful learning outcomes. Educators need to use various strategies to keep students engaged and interested in the course material. One approach is to incorporate active learning techniques, such as group discussions, case studies, and problem-solving activities, which have been shown to improve student engagement and understanding [10]. Additionally, using multimedia tools, such as videos, animations, and interactive simulations, can also enhance student learning [42].

Another important aspect of conducting effective classroom sessions is providing prompt and constructive feedback to students. Feedback can help students identify areas where they need to improve and provide motivation for further learning [43]. Educators can provide feedback in various ways, such as through graded assignments, quizzes, or in-class discussions.

Moreover, creating a positive classroom environment is also essential for effective teaching. Educators should encourage respect and diversity among students and foster a safe and inclusive learning environment [44]. Providing opportunities for student collaboration and interaction can also contribute to a positive classroom atmosphere [45].

Lastly, technology can be a useful tool for conducting effective classroom sessions, especially in the context of remote or hybrid learning. Virtual learning environments, online discussions, and digital collaboration tools are just a few examples of how technology can enhance student engagement and participation [46].

5.5 Evaluation and assessment methods

Evaluation and assessment are critical components of the teaching and learning process. It is essential to assess student learning outcomes to determine whether the teaching methods employed have been effective and to identify areas for improvement. Effective evaluation and assessment methods can provide valuable feedback to both students and educators, allowing for continuous improvement in teaching and learning.

There are several methods of evaluation and assessment that educators can employ. These include formative assessments, summative assessments, self-assessment, peer assessment, and authentic assessment [47]. Formative assessments are used to monitor student progress throughout the learning process, while summative assessments are used to evaluate student learning at the end of a unit or course. Self-assessment and peer assessment can be used to encourage student reflection and peer feedback. Authentic assessment methods, such as project-based assessments, can be used to assess student learning in real-world contexts.

Rubrics are also useful tools for evaluation and assessment, providing clear criteria for evaluating student work and promoting consistency in grading [48]. Technology can also be used to facilitate evaluation and assessment, such as through online quizzes and electronic grading systems [49].

In recent years, there has been an increased focus on the use of data analytics for evaluation and assessment in education. Data analytics can be used to identify patterns and trends in student learning outcomes, enabling educators to make informed decisions about teaching methods and curriculum development [50]. Additionally, the use of artificial intelligence and machine learning algorithms in assessment is becoming more prevalent, providing personalized feedback and adaptive learning experiences for students [51].

It is essential for educators to select appropriate evaluation and assessment methods that align with their learning objectives and teaching methods. The methods employed should be reliable, valid, and provide meaningful feedback to students. Additionally, educators should continuously assess and modify their evaluation and assessment methods to improve student learning outcomes and promote effective teaching.

Student feedback metrics and analysis: Student feedback was a key component of the evaluation process, providing insights into the effectiveness of the teaching approaches used in this study. The feedback metrics included:

- **Engagement levels:** Students were asked to rate their engagement in the course on a Likert scale ranging from 1 (not engaged) to 5 (highly engaged).
- **Teaching effectiveness:** Feedback forms evaluated aspects such as clarity of instruction, quality of teaching materials, and overall course organization.
- **Practical skills development:** Students assessed how well the course contributed to their understanding and application of electronics concepts in practical settings.
- **Achievement of learning outcomes:** Questions addressed the extent to which students felt the course helped them meet its stated objectives.

The analysis involved:

1. **Quantitative analysis:** Likert scale data were averaged to identify trends and compare feedback across the control and experimental groups.
2. **Qualitative analysis:** Open-ended responses were thematically analyzed to identify common patterns, suggestions, and areas for improvement.
3. **Comparative evaluation:** Feedback from the experimental group (active learning) was compared with that from the control group (traditional lecture) to assess differences in student perceptions and satisfaction.

The inclusion of these metrics provided actionable insights for refining teaching strategies and enhancing student outcomes in future iterations of the course.

6 BEST PRACTICES IN TEACHING ELECTRONICS

6.1 Incorporating real-world examples

Incorporating real-world examples into the teaching of electronics can be an effective way to engage students and help them understand how theoretical concepts apply in real-life situations. When selecting real-world examples, educators should consider the relevance to the course material, the level of complexity, and the potential for student interest and engagement. Real-world examples can be drawn from various industries, including healthcare, telecommunications, automotive, and renewable energy.

Recent studies, such as in [52], have highlighted the importance of incorporating real-world examples in the teaching of digital signal processing and electronics to improve student engagement, motivation, interest, and understanding.

To effectively incorporate real-world examples, educators can use a variety of teaching methods such as case studies, simulations, and projects. According to a study by Lamar et al. [53], the use of PBL that incorporates practical examples was effective in improving student learning outcomes in the teaching of power electronics.

In addition to improving student engagement and understanding, incorporating real-world and practical examples can also help prepare students for future careers in electronics-related fields. For example, a study by Sahin et al. [54] found that the use of real-world examples in the teaching of microcontroller-based systems improved students' practical skills and prepared them for future employment.

Therefore, educators should consider incorporating real-world examples into their teaching of electronics subjects and courses. By doing so, they can enhance student engagement, improve learning outcomes, and better prepare students for future careers in electronics-related fields.

6.2 Providing hands-on experience

In addition to incorporating real-world examples, providing hands-on experience is another best practice in teaching electronics subjects and courses. Hands-on experience allows students to apply theoretical concepts learned in class to practical situations, enhancing their understanding and retention of the material [55]. Hands-on experience can be provided through various methods, such as laboratory sessions, design projects, and field trips [56].

Providing hands-on experience is an essential component of teaching electronics subjects and courses. Students are better able to understand and retain concepts when they are given opportunities to apply what they have learned through practical projects and experiments [57]. To incorporate hands-on experience into electronics courses, educators can consider using PBL, laboratory experiments, simulations, and case studies.

Laboratory sessions are an important component of hands-on experience, as they allow students to work with real electronic devices and equipment, providing a practical understanding of how they work and how to troubleshoot problems [58]. Design projects are another effective method of providing hands-on experience, as they require students to apply theoretical knowledge to design and build functioning electronic systems [56]. Field trips to industrial sites or research centers can also provide valuable hands-on experience, allowing students to see firsthand how electronic systems are designed, manufactured, and implemented in real-world applications [58].

To ensure that hands-on experience is effective in enhancing student learning, educators should follow several best practices. First, educators should ensure that the hands-on activities are relevant to the course material and learning objectives. Second, educators should provide adequate resources and equipment for students to complete the hands-on activities. Third, educators should provide clear instructions and guidance for the hands-on activities, as well as opportunities for students to ask questions and receive feedback [55].

Incorporating hands-on experience in the teaching of electronics subjects and courses has been shown to enhance student learning and motivation [56]. By providing students with opportunities to apply theoretical concepts to practical situations, educators can help prepare them for careers in electronics and related fields.

6.3 Engaging students in collaborative activities

Collaborative activities can enhance students' engagement and learning outcomes by promoting active participation, problem-solving, and teamwork skills. In the context of electronics education, collaborative activities can include group projects, design challenges, and peer learning [59]. The use of digital tools and platforms can also facilitate collaborative activities in online and hybrid learning environments [60].

One example of a collaborative activity in electronics education is the use of PBL. PBL involves students working in teams to solve real-world problems, with a focus on hands-on experimentation and application of theoretical concepts [61]. Another example is the use of design challenges, which involve students in the process of designing and building electronic devices or systems [58].

Peer learning is also a valuable collaborative activity in electronics education. Peer learning involves students in a collaborative learning process, where they work together to develop their understanding of the subject matter [62]. This can be facilitated through group discussions, peer review, and peer feedback.

Overall, the incorporation of collaborative activities in electronics education can enhance student engagement and learning outcomes. However, educators need to ensure that these activities are well-designed, appropriately scaffolded, and aligned with the learning objectives of the course.

6.4 Flipped learning in digital electronics education

The study by Rubina Dutta et al. [63] investigates the impact of the flipped learning approach on students' motivation and academic performance in the context of the "Digital Electronics" course within engineering education. It begins by highlighting the advantages of the flipped classroom model, emphasizing the transformative learning experiences it offers through active student engagement and critical thinking. The research involved 66 students specializing in "Digital Electronics," employing the Keller method to evaluate enhanced motivation and online testing for performance assessment. The results of the analysis indicate significantly higher levels of student attention in the flipped classroom compared to traditional instruction, without a major change in perceived relevance, suggesting that students were more interested in learning. Moreover, the flipped approach led to notable increases in student confidence and satisfaction, which, in turn, contributed to enhanced performance in digital electronics. The study underscores the need for well-planned implementation of flipped learning activities in the educational process, emphasizing the importance of considering factors such as students' perception of educational material, their learning attitude, and critical thinking skills. Overall, the findings highlight the potential of the flipped learning model to boost student motivation, engagement, and academic outcomes in the field of digital electronics.

6.5 Encouraging critical thinking and problem-solving skills

Encouraging critical thinking and problem-solving skills is crucial for students to succeed in the field of electronics. To achieve this, educators should incorporate various instructional strategies and tools. For instance, in the Fundamentals of Microelectronics course, a variety of strategies and tools are employed to bridge theoretical concepts with practical applications, fostering a deeper understanding of core electronics principles.

One approach is to engage students in open-ended problem-solving activities that require them to analyze and synthesize information, identify patterns and relationships, and develop creative solutions to real-world problems [64, 65]. For example, students might be asked, "How would you design a rectifier circuit to maximize efficiency and minimize distortion for a given application?" or "What steps would you take to optimize the switching speed of a MOSFET in a low-power amplifier circuit?" These questions challenge students to connect theoretical knowledge to practical design tasks, enhancing their analytical thinking.

Another effective method is the use of case studies, which can provide students with an opportunity to apply their knowledge to real-world situations and develop their problem-solving skills [66]. For instance, a case study might involve analyzing the performance of a Zener diode voltage regulator under varying load conditions or evaluating design trade-offs in a Schottky diode used for high-frequency switching applications. Such scenarios encourage students to approach complex problems systematically, considering both technical and practical constraints.

In addition, the use of simulations and virtual labs can enhance students' problem-solving skills by allowing them to practice and apply their knowledge in a safe and controlled environment [67]. Lab activities in the course include using SPICE software to simulate the current-voltage characteristics of MOSFETs or to explore the transient response of diode clipper circuits. These simulations help students troubleshoot, analyze, and optimize circuit behavior while reinforcing their understanding of device principles.

Collaborative learning can also be effective in promoting critical thinking and problem-solving skills. By working in teams, students can share ideas, perspectives, and knowledge, which can lead to a more comprehensive understanding of the subject matter [68]. For example, students might collaborate on designing a small-signal MOSFET amplifier, balancing factors such as gain, bias stability, and linearity. This teamwork fosters the integration of diverse perspectives and ensures deeper learning outcomes.

Moreover, problem-based learning can encourage critical thinking and problem-solving skills by providing students with authentic and complex problems that require them to apply their knowledge and skills [69]. A PBL scenario might involve designing a power-efficient MOSFET-based switching circuit for a portable device, where students must consider heat dissipation, efficiency, and reliability. These activities allow students to navigate real-world constraints and develop practical solutions.

Finally, educators should encourage students to think critically by asking open-ended questions, challenging assumptions, and encouraging them to evaluate and analyze information. This can be achieved through class discussions, group projects, and other interactive activities that require students to think critically and reflect on their learning [70]. For instance, a classroom discussion might focus on comparing the trade-offs between using BJTs and MOSFETs in high-frequency amplifier circuits, prompting students to evaluate factors such as cost, efficiency, and performance.

By incorporating these strategies, the Fundamentals of Microelectronics course equips students with the critical thinking and problem-solving skills necessary for tackling real-world challenges in electronics engineering. These methods ensure that students can effectively analyze complex problems, develop innovative solutions, and contribute meaningfully to the field.

6.6 Creating a supportive learning environment

Creating a supportive learning environment is critical to the success of any course, including electronics. A positive learning environment can improve student motivation, engagement, and retention. Here are some best practices for creating a supportive learning environment in electronics courses:

- Encourage open communication and active listening: Create a classroom culture where students feel comfortable asking questions and sharing their thoughts and ideas. Active listening is an essential skill for creating a supportive environment where all students feel heard and valued.
- Use inclusive language and teaching practices: Be mindful of the language you use in the classroom and avoid using gendered or exclusive language. Use diverse examples and case studies to make the course materials more inclusive and relevant to a broader range of students.
- Provide feedback and support: Regular feedback is essential to help students track their progress and identify areas where they need additional support. Provide multiple opportunities for students to receive feedback, such as peer review, self-reflection, and one-on-one meetings.
- Foster a sense of community: Create opportunities for students to collaborate and work together, such as group projects, study groups, and peer tutoring. A sense of community can help students feel more connected to the course material and to each other, leading to increased engagement and motivation.

Some recent studies have explored the benefits of creating supportive learning environments in engineering courses. For example, Kulhanek et al. [71] found that creating a supportive learning environment improved student motivation and engagement in a first-year engineering course. Pirlo and Comfort [72] identified inclusive teaching practices, such as the use of diverse examples and case studies, as key to creating an inclusive learning environment in engineering courses. Lastly, existing studies, such as those cited in [73] and [74], indicate that collaborative learning activities, including group projects and peer review, can promote a sense of community and enhance student engagement in engineering courses.

6.7 Assessment of teaching approaches

In this study, a quasi-experimental design was employed to evaluate the impact of active learning strategies on student engagement, practical skills, and academic performance in an undergraduate electronics engineering course. Two pre-existing undergraduate classes were selected as the control group and experimental group, each comprising 50 students. The control group was taught using conventional lecture-based methods, while the experimental group was exposed to active learning approaches, including flipped classroom techniques, PBL, and simulation software integration.

These specific active learning strategies were chosen based on their alignment with the course objectives and their demonstrated effectiveness in prior research. Flipped classroom techniques encourage pre-class preparation, freeing up class time for interactive discussions and problem-solving. PBL helps students apply theoretical knowledge to real-world problems, fostering teamwork and critical thinking. Simulation software integration bridges the gap between theory and practical application, providing hands-on experience with tools such as SPICE and MATLAB. Together, these strategies were selected to enhance engagement, improve practical skills, and support deeper learning outcomes in electronics education.

Group selection. The control and experimental groups were pre-existing undergraduate classes enrolled in the same course during the same semester. Selection was based on comparable size and course structure to ensure equivalence. Random assignment was not feasible due to logistical constraints, but both groups followed the same syllabus and learning objectives.

Student demographics and background knowledge. The students participating in this study were enrolled in the Fundamentals of Microelectronics course, a core requirement typically taken during the third year of an undergraduate EE program. All students had successfully completed the prerequisite course, Electric Circuits 1, which focuses on basic circuit theory and analysis. As a result, while students entered the course with foundational knowledge in general circuit analysis, they had no prior exposure to electronics-specific topics, such as semiconductor devices, amplifier design, or microelectronic systems.

The uniform progression of students through the curriculum ensures a consistent baseline of preparedness across the cohort, minimizing variability in prior knowledge as a factor influencing learning outcomes. Additionally, as per university policy, individual student GPA data was not accessible to the instructor. This policy emphasizes the equity of instructional practices by focusing on course-level assessment rather than individual academic histories.

This context highlights that the observed differences in outcomes between the experimental and control groups are attributable to the teaching methodologies implemented, rather than disparities in prior knowledge or academic performance. Future studies could incorporate optional, anonymized demographic or academic performance data to further explore the relationship between background knowledge and the effectiveness of active learning strategies.

Data collection. Data was collected to evaluate student performance across four metrics: overall course performance, practical skills, student engagement, and exam scores. Performance was measured through graded assessments, engagement was assessed via surveys, and practical skills were evaluated through laboratory assignments and projects.

Assessment tools and evaluation metrics. To evaluate the effectiveness of the teaching approaches, various assessment tools were employed, each aligned with specific course objectives:

1. **Exams:**
    - Exams were designed to assess theoretical understanding and application of electronics concepts, such as circuit analysis, signal processing, and system design.
    - The exam questions were mapped to the course objectives and learning outcomes, ensuring coverage of both foundational knowledge and problem-solving skills.
    - Reliability was maintained by using a standardized grading rubric, and validity was ensured through expert review by faculty members specializing in electronics education.
2. **Practical assessments:**
    - Laboratory assignments and projects were used to evaluate students' ability to apply theoretical knowledge to real-world scenarios.
    - These tasks required students to design, simulate, and analyze electronic circuits using tools such as SPICE and MATLAB, directly reflecting the practical skills outlined in the course objectives.
    - Assessments were scored using detailed rubrics focusing on design accuracy, innovation, and adherence to the specifications.
3. **Student feedback surveys:**
    - Engagement levels were assessed using a course evaluation survey administered at the end of the semester. The survey included standardized questions designed to evaluate student perceptions of the course and the instructor. Key aspects assessed included:
        - Interest in the subject.
        - Motivation to engage with course content.
        - Perceived value and alignment of learning activities with real-life applications.
    - The survey items were aligned with institutional evaluation practices and mapped to course objectives, ensuring clarity and relevance.
    - Quantitative feedback was collected using a 5-point Likert scale, allowing for statistical aggregation and comparison. Open-ended questions provided qualitative insights into strengths, weaknesses, and improvement suggestions for the course and the instructor.
    - While this study did not formally calculate metrics such as Cronbach's Alpha for reliability, the survey design was guided by established best practices in education evaluation. Comparative analysis, as seen in institutional evaluations, could be explored in future studies to benchmark and validate the findings.
4. **Performance metrics:**
    - Metrics such as percentage improvements in exam scores, project outcomes, and engagement survey results were calculated and compared between the control and experimental groups.
    - These metrics were chosen to provide a clear, quantitative measure of the effectiveness of active learning strategies.

Analysis approach. To evaluate the effectiveness of active learning strategies, percentage improvements were calculated between the control and experimental groups for the selected metrics. These improvements provided clear trends and actionable insights. Formal statistical tests (e.g., t-tests or ANOVA) were not performed, as the primary goal of this study was to highlight the practical impact of teaching strategies through observable differences. The decision not to conduct statistical tests reflects the study's focus on providing accessible evidence for instructors and educators while acknowledging that statistical analyses could add further rigor in future research.

Transparency and rationale. The decision not to conduct statistical tests was made to focus on presenting accessible, practical evidence of the trends observed. While statistical analyses could add further rigor, this study aims to offer educators a straightforward evaluation of the benefits of active learning methods.

Instructor training and experience. The successful implementation of active learning strategies often depends on the instructor's expertise and familiarity with these methods. In this study, the instructors for both the control and experimental groups possessed significant teaching experience in electronics engineering. While no formal training in active learning techniques was conducted specifically for this study, the instructor for the experimental group had prior experience in using flipped classroom methods, PBL, and simulation-based teaching.

To ensure consistency in the teaching approach, the experimental group instructor was provided with guidelines and resources for integrating active learning strategies effectively. These resources included sample lesson plans, case studies, and simulation tools designed to facilitate active engagement and practical application of concepts.

The potential impact of instructor experience on the study outcomes should be considered a limitation, as differences in familiarity with active learning techniques may influence the observed improvements in the experimental group. Future research should explore the effects of standardized training for instructors in active learning methods, as this could further enhance the consistency and scalability of such approaches.

Table 2. Comparative assessment of teaching approaches on student learning outcomes

Metric	Control Group	Experimental Group	Improvement
Overall Course Performance (Average Score)	75	86.25	15%
Practical Skills Application (Average Score)	80	96	20%
Student Engagement (Survey Score)	70	80	14%
Exam Scores (Average Score)	78	84	8%

Table 2 presents the comparative assessment of traditional lecture-based teaching (control group) versus active learning strategies (experimental group) on student learning outcomes in an undergraduate electronics-related course, titled Fundamentals of Microelectronics. The table highlights the improvements observed in the experimental group, including a 15% increase in overall course performance, a 20% enhancement in practical skills application, a 14% rise in student engagement, and an 8% improvement in average exam scores compared to the control group. These findings suggest that integrating active learning strategies can significantly enhance learning outcomes in electronics education.

Results from this study align with prior research on active learning strategies. For example, Dutta et al. [63] observed similar gains in engagement and academic performance in flipped classrooms for digital electronics courses. Additionally, Alam [29] highlighted the value of simulation-based learning in enhancing practical skills, which parallels the improvements observed in this study's experimental group. These findings not only corroborate the broader effectiveness of active learning strategies but also highlight their specific benefits in the context of electronics education, where the integration of theoretical and practical components is critical.

Practical applications. The findings of this study have significant implications for teaching methodologies in electronics education and other STEM disciplines. Educators can apply the active learning strategies described here to courses that involve complex theoretical concepts combined with practical applications. For example:

- **Flipped classroom techniques:** In courses such as digital electronics or control systems, pre-class materials can include video lectures or guided simulations to help students grasp foundational concepts. During class, educators can focus on problem-solving exercises, group discussions, and hands-on activities.
- **Simulation tools:** Tools such as SPICE or MATLAB can be integrated into circuit analysis or signal processing courses to allow students to explore practical scenarios and develop their technical skills interactively.
- **Project-based learning:** Courses such as embedded systems design or robotics can benefit from team-based projects, where students apply theoretical knowledge to real-world challenges, such as developing prototypes or solving engineering problems.

By incorporating these approaches, instructors can create dynamic, engaging learning environments that foster both conceptual understanding and practical expertise.

This study goes beyond a simple synthesis of existing literature by offering empirical evidence derived from a quasi-experimental setup. The results from the control and experimental groups underscore the tangible benefits of active learning strategies in electronics education. These findings were interpreted within the framework of constructivist learning theory, which posits that students learn more effectively when they are actively engaged in the learning process. This theoretical grounding supports the observed improvements in student outcomes and further validates the practical application of these teaching methods.

The comparative analysis conducted in this study contributes to the ongoing discourse on active learning in engineering education by providing concrete evidence of its effectiveness. Specifically, the observed improvements in practical skills, engagement, and exam performance provide a strong case for the broader adoption of active learning strategies in electronics courses. These findings are consistent with prior research, such as Lehtovuori et al. [75], which demonstrated that active learning approaches in EE foundational studies significantly enhanced students' engagement and practical skills application. Their work also highlighted the potential of these methods to improve exam performance, further validating the practical value of active learning strategies in traditionally challenging subject areas.

Study limitations. While this study provides valuable insights into the effectiveness of active learning strategies, certain limitations should be noted:

1. **Sample size:** The study involved a relatively small sample size (50 students in each group), which may limit the generalizability of the findings to larger populations.

2. **Selection bias:** The control and experimental groups were pre-existing classes, not randomly assigned, which introduces the possibility of selection bias.
3. **Single institution:** The study was conducted at a single institution, which may reduce the applicability of the results to other universities or contexts with different student demographics or resources.
4. **Focus on electronics education:** While the results are directly applicable to electronics courses, their relevance to other STEM disciplines may require further investigation.
5. **Longitudinal impact and knowledge retention:** While this study highlights the immediate benefits of active learning strategies on student engagement, practical skills, and academic performance in the Fundamentals of Microelectronics course, it does not evaluate the long-term retention of these gains. Existing studies, such as those cited in [10] and [76], indicate that active learning strategies may enhance long-term retention by promoting deeper engagement and problem-solving. However, further research is necessary to validate these findings in the context of electronics education. Future studies could include follow-up assessments conducted several months or even years after course completion to measure the durability of learning outcomes. Additionally, longitudinal analyses could explore the impact of active learning on students' career readiness and professional development in the field of electronics engineering. These insights would provide a more comprehensive understanding of the long-term value of active learning strategies.

Future studies with larger, more diverse samples and multi-institutional collaborations could address these limitations, providing a broader understanding of active learning strategies' impact.

7 CONCLUSION

In conclusion, the evolving landscape of EE education demands a multifaceted approach to teaching electronics, one that transcends traditional lecture-based methods to embrace active learning, collaboration, and real-world engagement. This paper, focused on the Fundamentals of Microelectronics course, has elucidated several pedagogical strategies that, when effectively implemented, foster a deep understanding of electronics principles and prepare students for the complexities of the engineering profession. The quasi-experimental design employed in this study provides compelling evidence that the integration of PBL, simulation software, and flipped classroom techniques can significantly enhance student engagement, practical skills, and overall course performance. By integrating real-world examples, providing hands-on experiences, facilitating collaborative projects, and establishing industry partnerships, educators can significantly enhance student motivation, engagement, and learning outcomes.

The conclusion of this study is firmly grounded in the data collected through a comparative analysis of two distinct teaching methods. The observed 15% improvement in overall course performance and 20% enhancement in practical skills among students in the experimental group underscore the effectiveness of active learning strategies. These findings provide new insights into the specific benefits of integrating flipped classrooms, PBL, and simulation tools in electronics education, offering a clear pathway for future instructional design in engineering education.

Future research should aim to further quantify the impacts of these strategies, explore the integration of emerging technologies, and investigate the long-term effects on student careers in the rapidly advancing field of electronics. Longitudinal studies tracking skill retention, performance in advanced courses, and application in professional contexts could provide deeper insights into the enduring impact of active learning strategies. These assessments will help refine instructional practices and ensure that the benefits of these methods extend well beyond the classroom.

While this study demonstrates significant improvements through active learning strategies, its scope is limited to one undergraduate course and does not include longitudinal data. Addressing these limitations in future research could provide a more comprehensive understanding of these strategies' long-term effects.

Ultimately, by adopting these recommended practices, educators will not only improve the educational experience for undergraduate engineering students but also equip them with the skills necessary to thrive in their future careers. Furthermore, these findings contribute to the broader discourse on the evolving role of active learning in STEM education, highlighting its potential to shape the next generation of engineers and innovators.

8 ACKNOWLEDGMENTS

This work was supported by United Arab Emirates University (UPAR) with Fund code 12N169.

9 CONFLICT OF INTEREST STATEMENT

The author declares that there is no conflict of interest.

10 REFERENCES

[1] Michael Prince, "Does active learning work? A review of the research," *Journal of Engineering Education*, vol. 93, no. 3, pp. 223–231, 2004. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x

[2] L. S. Vygotsky and M. Cole, *Mind in Society: Development of Higher Psychological Processes*. Cambridge: Harvard University Press, 1978.

[3] A. G. Spatioti, I. Kazanidis, and J. Pange, "A comparative study of the ADDIE instructional design model in distance education," *Information*, vol. 13, no. 9, p. 402, 2022. https://doi.org/10.3390/info13090402

[4] J. Michael, "Where's the evidence that active learning works?" *Advances in Physiology Education*, vol. 30, no. 4, pp. 159–167, 2006. https://doi.org/10.1152/advan.00053.2006

[5] Z. Tasir, J. Harun, S. A. H. S. Hassan, and K. M. Yusof, "Effective strategies for integrating e-learning in problem-based learning for engineering and technical education," Regional Conference on Engineering Education, Johor, Malaysia, 2005.

[6] A. Kolmos, F. K. Fink, and L. Krogh, "The Aalborg PBL model: Progress, diversity and challenges," *Higher Education*, vol. 48, no. 2, pp. 157–176, 2004.

[7] D. Seo and D. Mangra, "Project-based learning of digital logic circuit design," in *2017 Mid-Atlantic Section Fall Conference*, 2017.

[8] L. Abeysekera and P. Dawson, “Motivation and cognitive load in the flipped classroom: definition, rationale and a call for research,” *Higher Education Research & Development*, vol. 34, no. 1, pp. 1–14, 2015. https://doi.org/10.1080/07294360.2014.934336

[9] D. R. Garrison and H. Kanuka, “Blended learning: uncovering its transformative potential in higher education,” *The Internet and Higher Education*, vol. 7, no. 2, pp. 95–105, 2004. https://doi.org/10.1016/j.iheduc.2004.02.001

[10] S. Freeman *et al.*, “Active learning increases student performance in science, engineering, and mathematics,” *Proceedings of the National Academy of Sciences*, vol. 111, no. 23, pp. 8410–8415, 2014. https://doi.org/10.1073/pnas.1319030111

[11] R. R. Hake, “Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses,” *American Journal of Physics*, vol. 66, no. 1, pp. 64–74, 1998. https://doi.org/10.1119/1.18809

[12] D. A. Kolb, *Experiential Learning: Experience as the Source of Learning and Development*. New Jersey, NJ: FT Press, 2014.

[13] J. González, L. Reitman, T. Stagno, E. Mandado, and A. Salaverría, “An interactive system for teaching electronics,” in *EdMedia + Innovate Learning*, Association for the Advancement of Computing in Education (AACE), 2001, pp. 608–612.

[14] National Academy of Engineering, *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: National Academies Press, 2004.

[15] M. Rifkin, “Addressing underrepresentation: Physics teaching for all,” *The Physics Teacher*, vol. 54, no. 2, pp. 72–74, 2016. https://doi.org/10.1119/1.4940167

[16] N. R. Poole, “The application of simulators in teaching digital electronics,” *Engineering Science & Education Journal*, vol. 3, no. 4, pp. 177–184, 1994.

[17] O. F. Avilés, R. D. Hernández, and J. D. García, “Project based learning applied to teaching mechatronics,” *International Journal of Applied Engineering Research*, vol. 13, no. 22, pp. 15574–15579, 2018.

[18] D. Kokotsaki, V. Menzies, and A. Wiggins, “Project-based learning: A review of the literature,” *Improving Schools*, vol. 19, no. 3, pp. 267–277, 2016. https://doi.org/10.1177/1365480216659733

[19] D. H. J. M. Dolmans, de Grave, I. H. A. P. Wolfhagen, and C. P. M. van der Vleuten, “Problem-based learning: Future challenges for educational practice and research,” *Medical Education*, vol. 49, no. 5, pp. 461–468, 2015.

[20] A. Kolmos, E. De Graaff, and X. Du, “Diversity of PBL–PBL learning principles and models,” in *Research on PBL Practice in Engineering Education*, 2009, pp. 9–21. https://doi.org/10.1163/9789087909321_003

[21] Y. Chen, Y. Wang, Kinshuk, and N.-S. Chen, “Is FLIP enough? Or should we use the FLIPPED model instead?” *Computers & Education*, vol. 79, pp. 16–27, 2014. https://doi.org/10.1016/j.compedu.2014.07.004

[22] S. L. Hotle and L. A. Garrow, “Effects of the traditional and flipped classrooms on undergraduate student opinions and success,” *Journal of Professional Issues in Engineering Education and Practice*, vol. 142, no. 1, p. 05015005, 2016. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000259

[23] R. Castedo, L. M. López, M. Chiquito, J. Navarro, J. D. Cabrera, and M. F. Ortega, “Flipped classroom—comparative case study in engineering higher education,” *Computer Applications in Engineering Education*, vol. 27, no. 1, pp. 206–216, 2019. https://doi.org/10.1002/cae.22069

[24] M. J. Lage, G. J. Platt, and M. Treglia, “Inverting the classroom: A gateway to creating an inclusive learning environment,” *The Journal of Economic Education*, vol. 31, no. 1, pp. 30–43, 2000. https://doi.org/10.1080/00220480009596759

[25] J. Moraros, A. Islam, S. Yu, R. Banow, and B. Schindelka, "Flipping for success: Evaluating the effectiveness of a novel teaching approach in a graduate level setting," *BMC Medical Education*, vol. 15, pp. 1–10, 2015. https://doi.org/10.1186/s12909-015-0317-2

[26] C. J. Bonk and C. R. Graham, *The Handbook of Blended Learning: Global Perspectives, Local Designs*. San Francisco, CA: John Wiley & Sons, 2012.

[27] J. E. Froyd and M. W. Ohland, "Integrated engineering curricula," *Journal of Engineering Education*, vol. 94, no. 1, pp. 147–164, 2005. https://doi.org/10.1002/j.2168-9830.2005.tb00835.x

[28] M. J. Prince and R. M. Felder, "Inductive teaching and learning methods: Definitions, comparisons, and research bases," *Journal of Engineering Education*, vol. 95, no. 2, pp. 123–138, 2006. https://doi.org/10.1002/j.2168-9830.2006.tb00884.x

[29] A. Alam, "Leveraging the power of 'modeling and computer simulation' for education: An exploration of its potential for improved learning outcomes and enhanced student engagement," in *2023 International Conference on Device Intelligence, Computing and Communication Technologies (DICCT)*, 2023, pp. 445–450. https://doi.org/10.1109/DICCT56244.2023.10110159

[30] G. P. Wiggins and J. McTighe, *Understanding by Design* (2nd ed.). Alexandria, VA: ASCD, 2005.

[31] M. C. A. Dacuycuy, J. K. M. Rabago, C. G. Paguyo, S. R. I. Fernando, and R. C. S. Lasaten, "Constructivist materials in teaching selected topics in the contemporary world course," *South Asian Journal of Social Studies and Economics*, vol. 18, no. 4, pp. 21–40, 2023. https://doi.org/10.9734/sajsse/2023/v18i4663

[32] C. Ydesen, A. L. Milner, T. Aderet-German, E. G. Caride, and Y. Ruan, "Researching educational assessment and inclusive education," in *Educational Assessment and Inclusive Education: Paradoxes, Perspectives and Potentialities,* Palgrave Macmillan, Cham, 2023, pp. 39–63. https://doi.org/10.1007/978-3-031-19004-9_2

[33] C. E. Scott, L. E. Green, and D. L. Etheridge, "A comparison between flipped and lecture-based instruction in the calculus classroom," *Journal of Applied Research in Higher Education*, vol. 8, no. 2, pp. 252–264, 2016. https://doi.org/10.1108/JARHE-04-2015-0024

[34] A. W. Chickering and Z. F. Gamson, "Seven principles for good practice in undergraduate education," *AAHE Bulletin*, vol. 39, no. 7, pp. 3–7, 1987.

[35] D. W. Johnson and R. T. Johnson, *Learning Together and Alone: Cooperative, Competitive, and Individualistic Learning*. New Jersey, NJ: Prentice-Hall, Inc., 1987.

[36] K. J. Kim, C. J. Bonk, and E. Oh, "The present and future state of blended learning in workplace learning settings in the United States," *Performance Improvement*, vol. 47, no. 8, pp. 5–16, 2008. https://doi.org/10.1002/pfi.20018

[37] K. D. Tanner, "Promoting student metacognition," *CBE-Life Sciences Education*, vol. 11, no. 2, pp. 113–120, 2012. https://doi.org/10.1187/cbe.12-03-0033

[38] A. S. Al-Adwan, M. Nofal, H. Akram, N. A. Albelbisi, and M. Al-Okaily, "Towards a sustainable adoption of e-learning systems: The role of self-directed learning," *Journal of Information Technology Education: Research*, vol. 21, pp. 245–267, 2022. https://doi.org/10.28945/4980

[39] S. Biswas *et al.*, "Institutionalizing evidence-based STEM reform through faculty professional development and support structures," *International Journal of STEM Education*, vol. 9, no. 1, pp. 1–23, 2022. https://doi.org/10.1186/s40594-022-00353-z

[40] V. D. Jeyabalan and P. C. Cynthia, "Information and communication technology for teacher development," in *Continuing Professional Development of English Language Teachers,* S. P. Dhanavel, Eds., Springer, Singapore, 2022, pp. 151–167. https://doi.org/10.1007/978-981-19-5069-8_10

[41] J. Cuevas, "Is learning styles-based instruction effective? A comprehensive analysis of recent research on learning styles," *Theory & Research in Education*, vol. 13, no. 3, pp. 308–333, 2015. https://doi.org/10.1177/1477878515606621

[42] R. E. Mayer and R. Moreno, "Nine ways to reduce cognitive load in multimedia learning," *Educational Psychologist*, vol. 38, no. 1, pp. 43–52, 2003. https://doi.org/10.1207/S15326985EP3801_6

[43] J. Hattie and H. Timperley, "The power of feedback," *Review of Educational Research*, vol. 77, no. 1, pp. 81–112, 2007. https://doi.org/10.3102/003465430298487

[44] N. Henderson and M. M. Milstein, *Resiliency in Schools: Making It Happen for Students and Educators*. Thousand Oaks, CA: Corwin Press, 2003.

[45] D. W. Johnson and R. T. Johnson, "Student motivation in co-operative groups: Social interdependence theory," in *Co-Operative Learning: The Social and Intellectual Outcomes of Learning in Groups*, R. M. Gillies and A. F. Ashman, Eds., Routledge, 2003, pp. 136–176.

[46] L. Darling-Hammond, L. Flook, C. Cook-Harvey, B. Barron, and D. Osher, "Implications for educational practice of the science of learning and development," *Applied Developmental Science*, vol. 24, no. 2, vol. 97–140, 2020. https://doi.org/10.1080/10888691.2018.1537791

[47] J. McTighe and K. O'Connor, "Seven practices for effective learning," *Assessment*, vol. 63, no. 3, 2005.

[48] H. Andrade, Y. Du, and K. Mycek, "Rubric-referenced self-assessment and middle school students' writing," *Assessment in Education: Principles, Policy & Practice*, vol. 17, no. 2, pp. 199–214, 2010. https://doi.org/10.1080/09695941003696172

[49] R. E. Ferdig, E. Baumgartner, R. Hartshorne, R. Kaplan-Rakowski, and C. Mouza, Eds., *Teaching, Technology, and Teacher Education During the COVID-19 Pandemic: Stories From the Field.* Waynesville, NC: Association for the Advancement of Computing in Education, 2020.

[50] K. R. Koedinger, R. S. Baker, K. Cunningham, A. Skogsholm, B. Leber, and J. Stamper, "A data repository for the EDM community: The PSLC DataShop," *Handbook of Educational Data Mining*, vol. 43, pp. 43–56, 2010.

[51] J. Gardner, M. O'Leary, and L. Yuan, "Artificial intelligence in educational assessment: 'Breakthrough? Or buncombe and ballyhoo?'" *Journal of Computer Assisted Learning*, vol. 37, no. 5, pp. 1207–1216, 2021. https://doi.org/10.1111/jcal.12577

[52] A. M. Deshpande, "Project based learning approach in digital signal processing course for increasing learners' cognitive and behavioral engagement to promote self-learning," *Journal of Engineering Education Transformations*, vol. 36, no. Special Issue 1, 2022. https://doi.org/10.16920/jeet/2022/v36is1/22177

[53] D. G. Lamar, P. F. Miaja, M. Arias, A. Rodríguez, M. Rodríguez, and J. Sebastián, "A project-based learning approach to teaching power electronics: Difficulties in the application of project-based learning in a subject of switching-mode power supplies," in *IEEE EDUCON 2010 Conference*, 2010, pp. 717–722. https://doi.org/10.1109/EDUCON.2010.5492509

[54] S. Sahin, M. Olmez, and Y. Isler, "Microcontroller-based experimental setup and experiments for SCADA education," *IEEE Transactions on Education*, vol. 53, no. 3, pp. 437–444, 2009. https://doi.org/10.1109/TE.2009.2026739

[55] I. A. Ukaegbu, E. Onyejegbu, F. N. Mokogwu, and R. C. Kizilirmak, "Simplified and inexpensive integrated simulation and hands-on experiments in teaching electronics instrumentation and measurement laboratory course," in *2023 IEEE Global Engineering Education Conference (EDUCON)*, 2023, pp. 1–3. https://doi.org/10.1109/EDUCON54358.2023.10125251

[56] F. Severance, M. Suchowski, and D. Miller, "Benefits of a hands on introduction to electrical and computer engineering," in *2003 Annual Conference*, 2003, pp. 8.264.1–8.264.10. https://doi.org/10.18260/1-2--12647

[57] C. K. Looi *et al.*, "Interest-Driven Creator Theory: Case study of embodiment in an experimental school in Taiwan," *Research and Practice in Technology Enhanced Learning*, vol. 18, pp. 1–34, 2023. https://doi.org/10.58459/rptel.2023.18023

[58] T. Z. Qi, "Industry Oriented Teaching and Learning strategies applied to the course within traditional engineering technology undergraduate program," in *2008 38th Annual Frontiers in Education Conference*, 2008, pp. F2E-1–F2E-4. https://doi.org/10.1109/FIE.2008.4720291

[59] B. F. Khaleel, K. B. Glory, R. Rajuri, and N. Akhtar, "Participatory approach in context of EFL learners-A study on perception of teachers and learners," *Eur. Chem. Bull.*, vol. 12, no. 3, pp. 450–468, 2023.

[60] R. Castro, "Blended learning in higher education: Trends and capabilities," *Education and Information Technologies*, vol. 24, pp. 2523–2546, 2019. https://doi.org/10.1007/s10639-019-09886-3

[61] P. M. Sadler, H. P. Coyle, and M. Schwartz, "Engineering competitions in the middle school classroom: Key elements in developing effective design challenges," *The Journal of the Learning Sciences*, vol. 9, no. 3, pp. 299–327, 2000. https://doi.org/10.1207/S15327809JLS0903_3

[62] S. Gamlath, "Peer learning and the undergraduate journey: A framework for student success," *Higher Education Research & Development*, vol. 41, no. 3, pp. 699–713, 2022. https://doi.org/10.1080/07294360.2021.1877625

[63] R. Dutta, A. Mantri, G. Singh, S. Malhotra, and A. Kumar, "Impact of flipped learning approach on students' motivation for learning digital electronics course," *Интеграция образования Integration of Education*, vol. 24, no. 3, pp. 453–464, 2020. https://doi.org/10.15507/1991-9468.100.024.202003.453-464

[64] M. S. Baldwin, R. O. Beltran, and E. Chernobilsky, "Enhancing thinking through problem-based learning approaches: International perspectives," Thomson Learning Asia, 2004.

[65] A. Olewnik, R. Yerrick, A. Simmons, Y. Lee, and B. Stuhlmiller, "Defining open-ended problem solving through problem typology framework," *International Journal of Engineering Pedagogy (IJEP)*, vol. 10, no. 1, pp. 7–30, 2020. https://doi.org/10.3991/ijep.v10i1.11033

[66] S. Anwar, "Use of engineering case studies to teach associate degree electrical engineering technology students," in *31st Annual Frontiers in Education Conference. Impact on Engineering and Science Education. Conference Proceedings (Cat. No.01CH37193)*, Reno, NV, USA, 2001, pp. S1G-8. https://doi.org/10.1109/FIE.2001.964008

[67] Z. Zaturrahmi, F. Festiyed, and E. Ellizar, "The utilization of virtual laboratory in learning: A meta-analysis," *Indonesian Journal of Science and Mathematics Education*, vol. 3, no. 2, pp. 228–236, 2020. https://doi.org/10.24042/ijsme.v3i2.6474

[68] W. W. S. Lee and M. Yang, "Effective collaborative learning from Chinese students' perspective: A qualitative study in a teacher-training course," *Teaching in Higher Education*, vol. 28, no. 2, pp. 221–237, 2023. https://doi.org/10.1080/13562517.2020.1790517

[69] Y. Liu and A. Pásztor, "Effects of problem-based learning instructional intervention on critical thinking in higher education: A meta-analysis," *Thinking Skills and Creativity*, vol. 45, p. 101069, 2022. https://doi.org/10.1016/j.tsc.2022.101069

[70] L. S. Behar-Horenstein and L. Niu, "Teaching critical thinking skills in higher education: A review of the literature," *Journal of College Teaching & Learning (TLC)*, vol. 8, no. 2, 2011. https://doi.org/10.19030/tlc.v8i2.3554

[71] A. Kulhanek, B. Butler, and C. A. Bodnar, "Motivating first-year engineering students through gamified homework," *Educational Action Research*, vol. 29, no. 5, pp. 681–706, 2021. https://doi.org/10.1080/09650792.2019.1635511

[72] R. Pirlo and D. A. Comfort, "Inclusive teaching techniques and in-class team activities: Explorations in group awareness, individual value, and changing mindset," 2023.

[73] M. Natarajarathinam, S. Qiu, and W. Lu, "Community engagement in engineering education: A systematic literature review," *Journal of Engineering Education*, vol. 110, no. 4, pp. 1049–1077, 2021. https://doi.org/10.1002/jee.20424

[74] H. Gharbaoui, K. Mansouri, and F. Poirier, "Improving student engagement and success in computer programming courses through social learning in online environments," *International Journal of Engineering Pedagogy (iJEP)*, vol. 14, no. 6, pp. 54–68, 2024. https://doi.org/10.3991/ijep.v14i6.48705

[75] A. Lehtovuori, M. Honkala, H. Kettunen, and J. Leppävirta, "Promoting active learning in electrical engineering basic studies," *International Journal of Engineering Pedagogy (iJEP)*, vol. 3, no. S3, pp. 5–12, 2013. https://doi.org/10.3991/ijep.v3iS3.2653

[76] M. Pinho-Lopes and J. Macedo, "Project-based learning to promote high order thinking and problem-solving skills in geotechnical courses," *International Journal of Engineering Pedagogy (iJEP)*, vol. 4, no. 5, pp. 20–27, 2014. https://doi.org/10.3991/ijep.v4i5.3535

11 AUTHOR

Falah Awwad, Ph.D., is a Professor in the Department of Electrical and Communication Engineering at the College of Engineering, United Arab Emirates University (UAEU), Al Ain, UAE. He also serves as the coordinator of the MSc Electrical Engineering program. Dr. Awwad earned his MSc and Ph.D. degrees in Electrical and Computer Engineering from Concordia University, Montreal, Canada, in 2002 and 2006, respectively. Dr. Awwad's research interests encompass VLSI circuits and systems, with a focus on hardware security, sensors, and biomedical applications. He has co-authored one book and two book chapters and published over 120 articles in prestigious journals and international conferences, including IEEE journals, Biosensors and Bioelectronics, and Scientific Reports. He holds two U.S. patents and has successfully secured over 23 research grants, serving as the principal investigator for 17 of them. In addition to his research contributions, Dr. Awwad has played a pivotal role in academia, consulting and serving on committees for various universities and research institutions in the UAE. He has significantly contributed to curriculum development and enhancement for undergraduate and graduate programs in electrical engineering, computer engineering, and cybersecurity. His ongoing projects focus on IoT security, energy-efficient computing, and advanced semiconductor devices (E-mail: f_awwad@uaeu.ac.ae).