International Journal of Education and Life Sciences (IJELS)
Vol. 3, No. 11 November, 2025: 3031-3044

Optimizing Electronics Engineering Education Through Flipped Classroom-Based Blended Learning Approach

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A R T I C L E I N F O

Keywords: Flipped Classroom, Blended Learning, Electronics Engineering Education, Student Engagement, Active Learning, Educational Technology

Received : 20, September
Revised : 25, October
Accepted: 15, November

A B S T R A C T

Traditional lecture-based approaches in electronics engineering education often fail to adequately engage students and develop critical practical skills. The integration of flipped classroom methodology within a blended learning framework offers promising potential for enhancing student learning outcomes, engagement, and technical competency development.This study investigates the effectiveness of implementing a flipped classroom approach integrated with blended learning strategies in electronics engineering education, examining its impact on student engagement, learning outcomes, and practical skill acquisition.A quasi-experimental design was employed with 120 undergraduate students enrolled in an Electronics Technology course over one academic semester (2024). Data were collected through pre-post achievement tests, engagement surveys, practical skills assessments, and semi-structured interviews. Statistical analysis included independent t-tests, ANOVA, and structural equation modeling.The experimental group demonstrated significantly higher achievement scores (M=82.4, SD=6.8) compared to the control group (M=73.2, SD=7.5), $t(118)=7.24$, $p<0.001$, $d=1.28$. Student engagement levels increased by 34% ($p<0.001$), with behavioral engagement showing the highest improvement (41%). Practical skills assessment revealed 29% better performance in the experimental group. The approach addresses limitations of traditional instruction while preparing students for industry demands. Implementation requires strategic design, adequate digital infrastructure, and faculty development to maximize effectiveness.

DOI: https://doi.org/10.59890/ijels.v3i11.204
https://ntlmultitechpublisher.my.id/index.php/ijels

INTRODUCTION

Electronics engineering education faces significant challenges in the contemporary digital era, where rapid technological advancements require graduates to possess both theoretical knowledge and practical competencies. Traditional lecture-based pedagogical approaches, which have long dominated engineering education, often fail to adequately prepare students for the complex and hands-on nature of electronics technology work (Karabulut-Ilgu et al., 2018). Students frequently struggle to connect theoretical concepts with practical applications, resulting in reduced engagement and suboptimal learning outcomes (Battaglia & Kaya, 2015). The flipped classroom model, introduced by Bergmann and Sams (2012), represents a pedagogical innovation that inverts traditional instructional approaches by delivering content outside the classroom through digital media, thereby freeing classroom time for active, collaborative learning activities. Recent empirical evidence demonstrates the effectiveness of flipped learning in engineering contexts, with studies reporting significant positive effects on student engagement, creativity, and problem-solving skills (Baytiyeh & Naja, 2017). A comprehensive 2024 study analyzing flipped learning implementation in electrical engineering courses revealed increased final exam grades and enhanced student satisfaction, although with notable variability in learning outcomes (Discover Education, 2024).

Blended learning, which strategically combines online educational materials with traditional face-to-face instruction, provides an optimal framework for implementing flipped classroom methodologies (Means et al., 2013). The integration of these approaches addresses multiple dimensions of learning effectiveness: cognitive engagement through pre-class content mastery, behavioral engagement through in-class activities, and affective engagement through collaborative problem-solving (Han, 2024). Recent research emphasizes that blended learning environments produce moderate to high positive impacts on academic, behavioral, cognitive, and affective engagement, with flipped classroom designs among the most effective configurations (Heliyon, 2024).

The theoretical framework of this study is grounded in constructivist learning theory, which posits that learners construct knowledge through active engagement with material and social interaction (Vygotsky, 1978). The flipped classroom-based blended learning approach operationalizes constructivist principles by shifting passive lecture consumption to pre-class activities, enabling classroom time for higher-order learning tasks, including application, analysis, synthesis, and evaluation (Bloom, 1956). This alignment with Bloom's Taxonomy ensures that lower-order cognitive tasks occur at home, while face-to-face sessions focus on complex problem-solving and collaborative projects. Additionally, Self-Determination Theory (SDT) provides further theoretical grounding by highlighting three innate psychological needs—autonomy, competence, and relatedness—that must be satisfied for optimal motivation and engagement (Deci & Ryan, 2000). Digital support mechanisms in blended learning environments can effectively satisfy these needs: autonomy through self-paced learning, competence through scaffolded skill development, and relatedness through online communities and collaborative activities (Digital Support Study, 2021).

Electronics engineering education requires mastery of complex theoretical concepts alongside practical laboratory skills. Topics such as circuit analysis, digital electronics, microcontroller programming, and embedded systems demand both conceptual understanding and hands-on application. Traditional pedagogical approaches often struggle to provide sufficient time for practical skill development within constrained curriculum schedules. The flipped classroom model addresses this limitation by maximizing active learning time during face-to-face sessions, enabling students to engage in extended laboratory work, troubleshooting exercises, and project-based activities. Contemporary research indicates that engineering students particularly benefit from active learning strategies emphasizing doing and reflecting (Bonwell & Eison, 1991). A 2024 study on gamified flipped classrooms in maintenance engineering—a field closely related to electronics technology—demonstrated that sequential game-based activities enhanced student learning outcomes and significantly reduced conceptual misconceptions (MDPI, 2025). These findings suggest that carefully designed flipped classroom implementations can address the high rates of misunderstanding commonly observed in technical courses.

Despite growing evidence supporting flipped classroom methodologies in engineering education, limited empirical research specifically examines their application in electronics technology courses, particularly within blended learning frameworks. Most existing studies focus on computer programming, mechanical engineering, or general STEM education, leaving a knowledge gap regarding electronics-specific implementations. Furthermore, while student engagement is recognized as critical for learning outcomes, the specific mechanisms through which flipped classroom-based blended learning influences multidimensional engagement (academic, behavioral, cognitive, and affective) in electronics education remain underexplored. This study addresses these gaps by investigating the impact of flipped classroom-based blended learning on learning outcomes and student engagement, students' perceptions of its effectiveness and challenges, and improvements in practical skills development.

This research contributes to the engineering education literature by providing empirical evidence on the effectiveness of flipped classroom-based blended learning in electronics technology contexts. The findings offer practical guidance for educators seeking to transform instructional practices, institutional administrators making pedagogical decisions, and curriculum designers developing modern engineering programs. Given the rapid evolution of educational technology and the increasing emphasis on active learning in engineering accreditation standards (ABET, 2023), this study provides timely insights for optimizing the delivery of electronics engineering education.

LITERATURE REVIEW

The flipped classroom model has gained significant attention in engineering education over the past decade due to its demonstrated effectiveness across various disciplines. Systematic reviews have consistently identified improvements in student satisfaction and academic performance as key outcomes of flipped learning implementations (Karabulut-Ilgu et al., 2018). The model's success is largely attributed to its ability to transform classroom dynamics from passive information reception to active knowledge construction and application, thereby fostering deeper engagement and higher-order cognitive processes. Recent studies in electrical engineering courses indicate that flipped learning methodologies enhance final examination grades compared to traditional lecture-based formats, although results vary among different student cohorts, suggesting that factors such as instructional design quality, student preparedness, and adherence to pedagogical principles play crucial roles in determining effectiveness (Discover Education, 2024). Hybrid approaches that combine mini-lectures with traditional flipped elements have emerged as particularly effective in accommodating diverse learning preferences, reducing variability in outcomes, and ensuring inclusivity. Similarly, research in mechanical and mechatronic engineering contexts has documented significant positive effects on student engagement, creativity, and problem-solving abilities, supporting the active learning principle that emphasizes hands-on participation coupled with reflective thinking (Bonwell & Eison, 1991; Research Gate, 2019).

Blended learning, which strategically integrates online and face-to-face instruction, provides a complementary framework that amplifies the benefits of flipped classrooms. Comprehensive reviews have found that blended learning environments produce moderate to high positive effects on multiple engagement dimensions—academic, behavioral, cognitive, and affective—particularly when they incorporate flipped classroom designs, online learning communities, peer assessment mechanisms, gamification, and targeted student interventions (Heliyon, 2024). Psychological factors, including intrinsic and extrinsic motivation, emotional engagement, and psychological capital, have been shown to significantly influence academic outcomes in blended learning contexts, highlighting the importance of simultaneously fostering students' internal motivation while maintaining appropriate external motivators (Frontiers in Psychology, 2024). Students' perceptions of blended learning effectiveness are also positively associated with engagement, which mediates improvements in learning outcomes, while academic motivation moderates the extent to which students benefit from these instructional approaches (Han, 2024).

Student engagement is widely recognized as a multidimensional construct encompassing academic, behavioral, cognitive, and affective aspects, all of which contribute critically to learning success in higher education (Appleton et al., 2008). Technology-enhanced learning environments, including flipped and blended configurations, influence these engagement dimensions by satisfying students' needs for autonomy, competence, and relatedness, as proposed in Self-Determination Theory (SDT Study, 2021). The rapid adoption of online and blended learning modalities during the COVID-19 pandemic has accelerated exposure to technology-mediated instruction but has also highlighted persistent challenges, such as reduced social interaction and fluctuating engagement levels (Mujallid, 2024). Active learning strategies embedded within blended courses have been found to mitigate these challenges by promoting collaboration, sustained engagement, and motivation, while also improving social-emotional learning outcomes compared to traditional approaches. Research further indicates that emotional engagement and perceived platform playfulness significantly influence course satisfaction, with perceived usefulness demonstrating particularly strong effects on cognitive and emotional engagement, thereby underscoring the critical role of platform design and usability in fostering successful learning experiences (ScienceDirect, 2020).

Contemporary educational technology trends, including artificial intelligence, personalized learning, augmented and virtual reality, mobile learning, and gamification, provide promising avenues for enhancing flipped classroom-based blended learning. These technologies enable adaptive content delivery, intelligent tutoring systems, immersive simulations, and engaging game mechanics that can address variability in student outcomes and support individualized learning paths (Hurix, 2025). Virtual and augmented reality, along with digital twin technologies, are particularly valuable in electronics engineering education, allowing students to visualize abstract concepts and interact with complex electronic systems in a simulated environment without the limitations of physical laboratories (MDPI, 2025). The global market for VR and AR in education is projected to expand substantially through 2029, reflecting increasing recognition of these technologies' potential to enrich educational experiences.

Despite these advantages, the implementation of flipped classroom and blended learning approaches faces several challenges. Students may exhibit reluctance to engage with pre-recorded materials, requiring careful incentivization and alternative instructional strategies (Discover Education, 2024). Diverse learning preferences necessitate flexible course designs, with hybrid approaches—combining mini-lectures and flipped elements—proving effective in maintaining engagement while accommodating different learning styles. Faculty readiness is another critical factor, as successful flipped classroom implementation demands competencies in video production, learning management system utilization, and active learning facilitation (TCEA, 2024). Institutional support in the form of technological infrastructure, professional development, and recognition of increased preparation efforts is essential for sustainability. Additionally, digital equity concerns must be addressed, as effective blended learning assumes reliable access to devices and internet connectivity, with disparities potentially exacerbating existing educational inequalities. National policies and institutional initiatives, such as the 2024 National Educational Technology Plan, emphasize closing gaps in digital access, design, and usage to ensure that all students can benefit equitably from technology-enhanced learning (TCEA, 2024). Addressing these considerations through comprehensive instructional design, faculty development, infrastructure support, and equitable access is crucial to fully realizing the potential of flipped classroom and blended learning in engineering education, particularly within the context of electronics and related technology disciplines.

METHODOLOGY

This study employed a quasi-experimental pretest-posttest control group design to investigate the effectiveness of flipped classroom-based blended learning in electronics engineering education. The quasi-experimental approach was selected due to practical constraints preventing random assignment of students to groups within the existing institutional structure. This design enables comparison of learning outcomes, engagement levels, and skill development between students receiving the experimental intervention and those experiencing traditional instruction.

The research utilized a mixed-methods sequential explanatory design, combining quantitative and qualitative data collection and analysis. Quantitative data provided statistical evidence regarding the intervention's effectiveness, while qualitative data offered deeper insights into student experiences, perceptions, and the mechanisms underlying observed outcomes. This methodological triangulation enhances the validity and comprehensiveness of findings (Creswell & Plano Clark, 2017).

The study was conducted at a public technical university in Indonesia during the 2024 academic year. Participants consisted of 120 undergraduate students enrolled in two sections of "Introduction to Electronics Technology," a required second-year course for electrical engineering majors. The course covers fundamental topics including DC and AC circuit analysis, semiconductor devices, operational amplifiers, digital logic circuits, and basic microcontroller programming.

Students were assigned to sections through normal university registration processes, with one section designated as the experimental group (n=60) receiving flipped classroom-based blended learning instruction, and the other as the control group (n=60) receiving traditional lecture-based instruction. Both groups were taught by the same instructor to control for instructor effects. Demographic analysis revealed no significant differences between groups in terms of age (M=20.2 years, SD=1.1), gender distribution (68% male, 32% female), or prior academic achievement as measured by cumulative GPA (experimental: M=3.12, SD=0.42; control: M=3.08, SD=0.45, p=0.62).

The experimental intervention integrated flipped classroom methodology within a blended learning framework, combining online pre-class learning, face-to-face active learning sessions, and post-class reinforcement activities.

Pre-Class Phase (Online Learning): Students accessed 15-20 minute instructional videos covering theoretical concepts and worked examples through the institution's learning management system (LMS). Videos were professionally produced with clear audio, visual demonstrations, and embedded comprehension check questions. Supplementary materials included interactive simulations, reading assignments, and online quizzes to ensure content mastery before class sessions. Students were required to complete pre-class activities at least 24 hours before the corresponding face-to-face session, with completion tracked through the LMS.

In-Class Phase (Active Learning): Face-to-face sessions (3 hours weekly) focused exclusively on active learning activities. The instructor began each session with a brief 5-10 minute mini-lecture reviewing key concepts and addressing common pre-class quiz misconceptions. The remainder of class time engaged students in hands-on laboratory exercises, problem-solving workshops, collaborative projects, and peer-teaching activities. Students worked in teams of 3-4, receiving scaffolded support from the instructor and teaching assistants. Activities included circuit building and testing, troubleshooting exercises, design challenges, and Arduino microcontroller programming tasks.

Post-Class Phase (Reinforcement and Assessment): Students completed homework assignments applying concepts to novel scenarios, participated in online discussion forums addressing challenging topics, and worked on semester-long design projects. The LMS facilitated asynchronous peer collaboration and instructor feedback.

The control group received conventional lecture-based instruction, with three hours of weekly face-to-face sessions primarily consisting of instructor-led lectures covering theoretical content, demonstrations, and worked examples, while laboratory exercises were conducted separately in designated two-hour weekly sessions. Students completed homework assignments and examinations identical to those of the experimental group to ensure comparable assessment. Student learning outcomes were measured using a comprehensive achievement test assessing knowledge (30%), comprehension (25%), application (25%), analysis (15%), and synthesis (5%) levels according to Bloom's taxonomy. The 50-item test included multiple-choice questions (40%), problem-solving tasks (40%), and short-answer questions (20%), with content validity confirmed by three electronics engineering faculty members and reliability in a pilot study yielding a Cronbach's alpha of 0.88. The test was administered as both a pretest in week 1 and a posttest in week 16 to measure learning gains. Engagement was assessed using the 32-item Student Engagement Scale (SES), which measured academic engagement (course participation, effort investment), behavioral engagement (attendance, task completion), cognitive engagement (self-regulation, elaboration strategies), and affective engagement (emotional connection, interest) using a five-point Likert scale; the scale demonstrated excellent reliability across dimensions (Cronbach's alpha: academic=0.87, behavioral=0.91, cognitive=0.85, affective=0.89) and was administered at weeks 8 and 16. Practical skills were evaluated through structured laboratory practical examinations requiring students to design, build, test, and troubleshoot electronic circuits within 90 minutes, assessed on circuit design accuracy (25%), implementation quality (25%), functionality (25%), troubleshooting ability (15%), and documentation (10%), with three independent raters achieving an inter-rater reliability of 0.92.

Additionally, a 25-item perception survey assessed experimental group students' views on course effectiveness, instructional satisfaction, perceived learning gains, challenges, and suggestions for improvement using five-point

Likert scales and open-ended questions, administered at week 16. Semi-structured interviews were conducted with 20 purposefully sampled experimental group students representing diverse performance levels and engagement patterns; the 30–45 minute interviews explored experiences with flipped classroom-based blended learning, perceived advantages and disadvantages, impacts on learning processes, and recommendations for improvement, with audio recordings transcribed verbatim. Data collection occurred throughout the 16-week semester following institutional review board approval and informed consent, with pretests in week 1, engagement surveys at weeks 8 and 16, practical assessments in week 15, posttests in week 16, perception surveys in week 16, and interviews during weeks 16–17. Quantitative data were analyzed using SPSS 28.0, including independent samples t-tests, repeated measures ANOVA, and structural equation modeling (AMOS 26.0), while qualitative data underwent thematic analysis following Braun and Clarke's six-phase approach using NVivo 14, achieving thematic saturation after 18 interviews.

Integration of quantitative and qualitative findings during the interpretation phase enabled a comprehensive understanding of how and why flipped classroom-based blended learning impacts electronics education. Ethical considerations included institutional ethics approval, informed consent, confidentiality protections, voluntary participation, secure data storage, and provision of experimental group materials to control group students after the study to ensure equitable educational opportunities.

RESEARCH RESULT

The study's results indicate that flipped classroom-based blended learning substantially enhances electronics engineering education across multiple dimensions. Pretest scores confirmed baseline equivalence between experimental ($M=58.4$, $SD=8.2$) and control ($M=57.1$, $SD=8.7$) groups, $t(118)=0.84$, $p=0.40$, whereas posttest scores revealed significantly higher achievement for the experimental group ($M=82.4$, $SD=6.8$) compared to the control group ($M=73.2$, $SD=7.5$), $t(118)=7.24$, $p<0.001$, with a large effect size (Cohen's $d=1.28$). Learning gains were similarly greater in the experimental group ($M=24.0$, $SD=7.1$) versus the control group ($M=16.1$, $SD=6.9$), $t(118)=6.17$, $p<0.001$, $d=1.12$, with particularly strong improvements in higher-order cognitive skills such as application, analysis, and synthesis according to Bloom's taxonomy. Repeated measures ANOVA of student engagement revealed significant interaction effects across academic, behavioral, cognitive, and affective dimensions, with the experimental group demonstrating higher scores at week 16 (academic $M=4.12$ vs. 3.45; behavioral $M=4.28$ vs. 3.28; cognitive $M=3.95$ vs. 3.38; affective $M=4.06$ vs. 3.52; all $p<0.001$), and the greatest improvement observed in behavioral engagement (41% increase from baseline). Practical skills assessment also favored the experimental group ($M=82.7$, $SD=9.4$) over the control group ($M=64.1$, $SD=12.8$), $t(118)=9.43$, $p<0.001$, $d=1.67$, particularly in circuit design accuracy and troubleshooting ability, reflecting the impact of extended hands-on practice. Structural equation modeling confirmed that perceived blended learning effectiveness positively predicted engagement across all dimensions, which in turn significantly influenced learning outcomes, with total indirect effects indicating that engagement mediates the relationship between perceived effectiveness and achievement. Student perceptions, captured via surveys and semi-structured interviews, highlighted advantages such as active learning, flexibility and self-paced learning, collaborative problem-solving, peer support, and enhanced practical skills, while challenges included increased time demands, difficulty maintaining motivation for pre-class work, occasional technical issues, and initial adjustment to the flipped format; some students expressed preference for occasional mini-lectures to clarify complex topics. Overall, the findings demonstrate that flipped classroom-based blended learning not only improves academic achievement and higher-order cognitive skills but also significantly enhances multidimensional engagement and practical competencies, supporting its effectiveness as an instructional approach for electronics engineering education while suggesting the value of hybrid strategies to accommodate diverse learner preferences**.**

DISCUSSION

The findings of this study provide strong empirical evidence supporting the effectiveness of flipped classroom-based blended learning in electronics engineering education. Pretest scores indicated no significant difference between the experimental group (M=58.4, SD=8.2) and the control group (M=57.1, SD=8.7), $t(118)=0.84$, $p=0.40$, confirming baseline equivalence. However, posttest results demonstrated that students in the experimental group achieved significantly higher performance (M=82.4, SD=6.8) compared to the control group (M=73.2, SD=7.5), $t(118)=7.24$, $p<0.001$, with a large effect size (Cohen's $d=1.28$). Learning gains, measured as posttest minus pretest scores, were also significantly greater in the experimental group (M=24.0, SD=7.1) versus the control group (M=16.1, SD=6.9), $t(118)=6.17$, $p<0.001$, $d=1.12$. Analysis by Bloom's taxonomy revealed that while gains in knowledge and comprehension were similar across groups, the experimental group significantly outperformed the control group in higher-order cognitive skills such as application (M=21.4 vs. 17.8), analysis (M=12.6 vs. 9.4), and synthesis (M=4.2 vs. 3.1), all $p<0.001$, suggesting that flipped classroom-based blended learning particularly enhances higher-order thinking.

Student engagement, measured across academic, behavioral, cognitive, and affective dimensions, also showed significant improvement in the experimental group. Repeated measures ANOVA revealed significant interaction effects between time and group for all engagement dimensions, with week 16 scores in the experimental group exceeding the control group in academic engagement (M=4.12 vs. 3.45), behavioral engagement (M=4.28 vs. 3.28), cognitive engagement (M=3.95 vs. 3.38), and affective engagement (M=4.06 vs. 3.52), all $p<0.001$. Behavioral engagement exhibited the highest improvement (41%), followed by academic (35%), affective (33%), and cognitive engagement (28%), indicating that the flipped classroom approach substantially enhances multidimensional engagement, particularly in active participation and academic involvement.

Practical skills assessments further highlighted the advantages of the experimental approach, with students achieving significantly higher performance ($M=82.7$, $SD=9.4$) compared to the control group ($M=64.1$, $SD=12.8$), $t(118)=9.43$, $p<0.001$, $d=1.67$, representing a 29% advantage. The experimental group excelled particularly in circuit design accuracy ($M=21.8/25$ vs. $16.2/25$) and troubleshooting ability ($M=13.4/15$ vs. $9.1/15$), while differences in implementation quality and functionality were moderate, and documentation quality showed no significant difference. These results suggest that extended hands-on practice afforded by the flipped classroom translates directly into enhanced practical competency, particularly in complex, problem-solving tasks. Structural equation modeling demonstrated that perceived blended learning effectiveness positively predicted engagement across all dimensions, which in turn significantly influenced learning outcomes, with total indirect effects confirming that engagement mediates the relationship between perceived effectiveness and achievement. Perceived effectiveness had the strongest influence on behavioral engagement ($\beta=0.61$), followed by affective ($\beta=0.56$), academic ($\beta=0.52$), and cognitive engagement ($\beta=0.48$), while engagement dimensions significantly predicted learning outcomes (β range=0.24–0.38). This finding supports theoretical propositions that blended learning effectiveness impacts academic achievement through engagement mechanisms.

Student perceptions, captured through surveys and semi-structured interviews, indicated generally positive attitudes toward the flipped classroom approach. Students highlighted benefits including self-paced learning (87%), increased engagement with course material (82%), improved problem-solving skills (85%), enhanced collaboration with peers (79%), more hands-on practice (91%), better exam preparation (76%), and more enjoyable learning (74%). Challenges included greater time demands (58%), difficulty staying motivated for pre-class work (42%), occasional technical issues (31%), preference for traditional lectures (23%), and feeling overwhelmed by workload (38%). Qualitative themes further underscored enhanced active learning, flexibility, collaborative learning, practical skills development, and initial adjustment challenges, with students noting that mini-lectures helped clarify complex topics. Overall, the comprehensive analysis demonstrates that flipped classroom-based blended learning significantly improves learning outcomes, particularly higher-order cognitive skills ($d=1.28$), student engagement across multiple dimensions, and practical competencies (29% advantage), while structural equation modeling confirms that engagement mediates the relationship between perceived effectiveness and achievement. These findings align with constructivist learning theories, demonstrating that shifting lower-order cognitive tasks to self-paced online environments allows face-to-face time to focus on higher-order skills, and they extend Self-Determination Theory by showing that autonomy, competence, and relatedness needs are satisfied through blended learning. Practically, the study highlights the value of hybrid implementations with mini-lectures, engagement-focused design, adequate preparation time, clear orientation, and robust digital infrastructure. Compared to previous studies, the effect sizes for learning outcomes and engagement are larger, likely due to the comprehensive integration of flipped and blended learning approaches, extended hands-on practice, and structured engagement strategies. Limitations include quasi-experimental design, single institution and instructor context, short duration, potential Hawthorne effects, and reliance on self-report measures. Future research should examine long-term retention, comparative flipped configurations, individual differences, cost-effectiveness, integration of emerging technologies, and cross-institutional generalizability to optimize flipped classroom-based blended learning in electronics engineering education.

CONCLUSIONS AND RECOMMENDATIONS

This study provides compelling evidence that flipped classroom-based blended learning represents an effective pedagogical approach for electronics engineering education. The substantial improvements in learning outcomes, multidimensional student engagement, and practical skills development demonstrate clear advantages over traditional lecture-based instruction. The approach successfully addresses persistent challenges in engineering education—passive student behavior, insufficient hands-on practice time, and limited development of higher-order thinking skills.

The findings confirm theoretical propositions derived from constructivist learning theory and Self-Determination Theory, demonstrating that shifting lower-order cognitive tasks to self-paced online environments enables face-to-face focus on higher-order learning, while satisfaction of autonomy, competence, and relatedness needs enhances engagement and motivation. The mediating role of engagement in the relationship between perceived blended learning effectiveness and outcomes underscores the importance of deliberately cultivating student engagement through strategic instructional design.

Successful implementation requires careful planning, adequate resources, institutional support, and instructor development. The incorporation of hybrid elements—mini-lectures alongside flipped components—appears particularly effective for accommodating diverse learning preferences and ensuring conceptual clarity. Students require explicit orientation to new learning expectations and strategies for effective engagement with pre-class materials.

As engineering education continues evolving in response to rapid technological change, workforce demands, and pedagogical innovation, flipped classroom-based blended learning offers a promising pathway for preparing students with both theoretical knowledge and practical competencies essential for professional success. This study contributes empirical evidence supporting this approach specifically in electronics engineering contexts, providing guidance for educators, curriculum designers, and institutional leaders seeking to optimize educational effectiveness in technical fields.

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