

The Role of Artificial Intelligence in Advancing Electrical Engineering Education: A Comprehensive Review

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Abstract

The rapid advancement of Artificial Intelligence (AI) has created new opportunities to transform traditional educational practices, particularly in technically intensive disciplines such as Electrical Engineering (EE). Conventional EE education often relies on fixed curricula, uniform instructional approaches, and manual assessment methods, which may not adequately address diverse learner needs, varying levels of prior knowledge, and different learning paces. Agentic Artificial Intelligence (Agentic AI), characterized by autonomous decision-making, goal-oriented reasoning, and adaptive learning capabilities, has emerged as a promising solution for creating personalized and learner-centered educational environments. This paper reviews the role of Agentic AI in Electrical Engineering education and examines its potential to enhance teaching, learning, assessment, and laboratory experiences. The study explores how intelligent tutoring systems, autonomous educational agents, virtual laboratories, learning analytics, and simulation-based platforms can support individualized learning pathways, provide real-time feedback, diagnose misconceptions, and facilitate hands-on experimentation in areas such as circuit analysis, power systems, control engineering, embedded systems, and renewable energy applications. Furthermore, the paper discusses the integration of Agentic AI with engineering tools such as MATLAB/Simulink, circuit simulators, and learning management systems to create adaptive and scalable educational ecosystems. The review also highlights key challenges associated with the adoption of Agentic AI, including system reliability, academic integrity, data privacy, explainability, faculty readiness, and ethical considerations. The findings suggest that, when implemented with appropriate governance and human oversight, Agentic AI can significantly improve student engagement, learning outcomes, practical competency development, and instructional efficiency. The paper concludes that Agentic AI represents a transformative paradigm for the future of Electrical Engineering education, enabling personalized, competency-based, and experiential learning while preparing students for the evolving demands of the engineering profession.

Index Terms: Agentic AI, Electrical Engineering Education, Intelligent Tutoring Systems, Personalized Learning, Virtual Laboratories, Learning Analytics, Adaptive Learning, Educational Technology

1. Introduction (Heading 1)

Traditional teaching and learning approaches in Electrical Engineering (EE) education have traditionally relied on fixed syllabi, uniform instructional pacing, lecture-centric delivery, and manual evaluation methods, which often limit personalization, timely formative feedback, and continuous skill development, particularly in technically intensive domains such as circuit theory, power systems, electrical machines, control engineering, digital signal processing, and embedded systems. These conventional models frequently struggle to address heterogeneous learner profiles, varying prior knowledge levels, and diverse learning speeds, resulting in gaps in conceptual understanding, limited practical exposure, and reduced student engagement. Consequently, recent research has increasingly focused on integrating agentic artificial intelligence, intelligent tutoring systems, learning analytics, and simulation-based environments to develop adaptive, learner-centered educational ecosystems capable of autonomously diagnosing misconceptions, planning individualized learning trajectories, generating targeted learning materials, orchestrating virtual and physical experiments, and monitoring academic progress in real time [1], [2]. Agentic AI systems differ from traditional rule-based or single-interaction educational tools in that they exhibit goal-driven autonomy, multi-step reasoning, and continuous adaptation, enabling them to function as persistent virtual mentors that can plan instructional strategies, execute interventions, evaluate outcomes, and refine subsequent actions without constant human supervision. Foundational research on intelligent tutoring systems demonstrates how explicit learner models, cognitive tracing, and domain-specific knowledge representations can be used to provide personalized scaffolding and feedback in engineering problem-solving contexts [3], [4], and these principles now form the backbone of modern agentic learning architectures. In Electrical Engineering education, such systems are particularly valuable because many learning outcomes depend on iterative experimentation, mathematical modeling, and hands-on troubleshooting, which are difficult to support effectively in large classrooms or resource-constrained laboratories. Recent surveys highlight how autonomous agents can coordinate multiple educational components—such as circuit simulators, learning management systems, automated grading engines, discussion forums, and virtual laboratories—to create integrated learning workflows that adapt to each student’s evolving needs [1], [6]. Several EE-specific implementations illustrate these trends; for example, intelligent tutors for circuit analysis guide learners through Kirchhoff’s laws, nodal and mesh analysis, and Thevenin/Norton equivalents using stepwise hints and adaptive problem sequencing [4], [7], while agent-supported virtual labs enable students to design, simulate, and test analog and digital circuits in SPICE-like environments with automated error diagnosis and corrective feedback [8], [9]. Furthermore, the integration of AI agents with MATLAB/Simulink, PSCAD, and other model-based design tools allows learners to conduct parameter sweeps, sensitivity analyses, and control-system tuning experiments under agent supervision, thereby strengthening both theoretical understanding and practical competence. In power systems education, agentic platforms have been employed to support load-flow studies, fault analysis, and renewable energy integration experiments, where the agent automatically configures simulations, interprets results, and recommends corrective strategies, thus reducing cognitive overload and enabling deeper conceptual learning. Similarly, in embedded systems and IoT-oriented EE programs, agentic tutors assist students in microcontroller programming, sensor integration, and communication protocol debugging by continuously monitoring code execution, hardware behavior, and energy consumption patterns. Recent frameworks such as EduAgent and AITEE demonstrate how multi-agent systems and large language models can be combined with symbolic reasoning modules and domain

simulators to create virtual mentors that support both students and instructors by providing lesson planning assistance, automated assessment, learning analytics dashboards, and reflective teaching feedback [9], [10]. These systems can generate adaptive quizzes, project rubrics, and remediation plans, enabling instructors to focus more on mentoring, research, and curriculum innovation. Moreover, learning analytics integrated within agentic platforms enable the continuous collection and interpretation of student interaction data, laboratory logs, and performance metrics, which supports evidence-based instructional decision-making and early identification of at-risk learners [2]. From a pedagogical perspective, agentic AI facilitates the shift from content-centered instruction to competency-based and mastery-oriented learning, where students progress upon demonstrating conceptual and practical proficiency rather than merely completing scheduled coursework. However, despite these promising capabilities, the literature consistently emphasizes several critical challenges that must be addressed to ensure sustainable and ethical adoption in EE education. System reliability and accuracy remain major concerns, as incorrect guidance in circuit design, power electronics, or laboratory safety procedures may lead to equipment damage or unsafe conditions, necessitating robust validation mechanisms and human-in-the-loop supervision [1], [5]. Academic integrity is another pressing issue, since highly autonomous agents can potentially generate complete solutions to assignments and projects, undermining learning objectives unless assessment designs emphasize conceptual reasoning, experimentation, and reflective reporting. Data privacy and governance are also central considerations, as agentic platforms collect large volumes of sensitive learner data, including performance records, behavioral traces, and sometimes biometric information in smart labs, requiring transparent policies and secure infrastructures [14]. Furthermore, explainability and transparency are essential for building instructor and student trust, especially in engineering disciplines where reasoning processes, mathematical derivations, and design trade-offs must be clearly articulated and verifiable. Faculty readiness and institutional support represent additional barriers, as effective deployment demands professional development, curriculum redesign, and technical integration with existing infrastructure, which may be challenging in resource-limited environments. Nevertheless, empirical studies and pilot implementations suggest that when these challenges are addressed through modular system design, instructor oversight, ethical guidelines, and continuous evaluation, agentic AI systems can significantly enhance learning outcomes, improve student motivation, reduce faculty workload, and enable scalable, high-quality Electrical Engineering education across diverse contexts [1], [10]. Overall, the existing body of literature indicates that agentic AI represents a natural evolution of intelligent tutoring and educational technology paradigms, offering a powerful means to integrate personalization, automation, and experiential learning within EE curricula, and positioning future engineers to develop not only technical expertise but also self-regulated learning skills essential for lifelong professional growth.

I. CURRENT SCENARIO OF AI IN ELECTRICAL ENGINEERING EDUCATION

The rapid evolution of Artificial Intelligence (AI), Large Language Models (LLMs), and autonomous software agents is reshaping higher education globally. Educational institutions are increasingly adopting AI-powered learning platforms to enhance personalization, automate assessment, improve student engagement, and support competency-based learning. According to recent reports by UNESCO, IEEE, and the World Economic Forum, AI-driven educational technologies are expected to become a core component of engineering education ecosystems by 2030.

Electrical Engineering (EE) education presents unique challenges due to its strong dependence on mathematical modeling, laboratory experimentation, circuit design, simulation studies, and project-based learning. Traditional classroom approaches often struggle to provide individualized support for large student populations. Agentic AI addresses these limitations by acting as an intelligent virtual mentor capable of understanding learner needs, planning instructional interventions, monitoring progress, and adapting learning pathways in real time.

Recent advancements in Large Language Models such as GPT-based systems, multi-agent educational frameworks, intelligent tutoring systems, and AI-integrated simulation environments have accelerated the deployment of Agentic AI in engineering education. Universities worldwide are experimenting with AI-supported virtual laboratories, automated grading systems, personalized learning assistants, and digital twin-based engineering laboratories.

The current educational landscape indicates a transition from teacher-centered instruction toward learner-centric and competency-based education. Agentic AI enables continuous assessment, adaptive content generation, predictive analytics for identifying at-risk learners, and autonomous orchestration of laboratory activities. These capabilities are particularly beneficial in Electrical Engineering domains such as circuit analysis, power systems, control engineering, renewable energy systems, and embedded system design.

Despite significant opportunities, challenges remain regarding system reliability, ethical governance, data privacy, explainability, and faculty readiness. Therefore, successful implementation requires robust validation mechanisms, human oversight, institutional policies, and continuous professional development for educators.

The convergence of Agentic AI, digital laboratories, learning analytics, and engineering simulation tools is expected to create intelligent educational ecosystems capable of delivering scalable, personalized, and industry-relevant Electrical Engineering education.

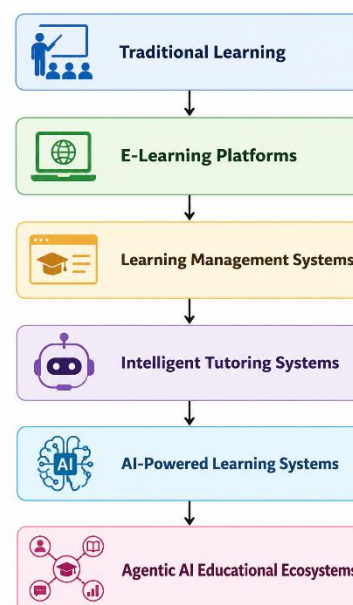


Figure 1. Evolution of Educational Technologies

The above figure 1 shows the Evolution from conventional teaching methods to autonomous Agentic AI-driven learning environments.

II. EASE OF USE

Artificial Intelligence (AI) is rapidly changing the way Electrical Engineering education is delivered. Traditional teaching methods often follow a fixed curriculum and provide the same learning experience to all students, regardless of their individual learning needs. Agentic AI introduces a new approach by acting as an intelligent assistant that can understand student requirements, provide personalized learning support, generate learning materials, conduct assessments, and offer real-time feedback.

Today, many universities and educational institutions are integrating AI-powered tools such as intelligent tutoring systems, virtual laboratories, learning analytics platforms, and simulation software into engineering education. In Electrical Engineering, Agentic AI helps students learn complex topics such as circuit analysis, power systems, control systems, electrical machines, and embedded systems through adaptive learning and guided experimentation. These systems can identify learning gaps, recommend suitable resources, and monitor student progress continuously.

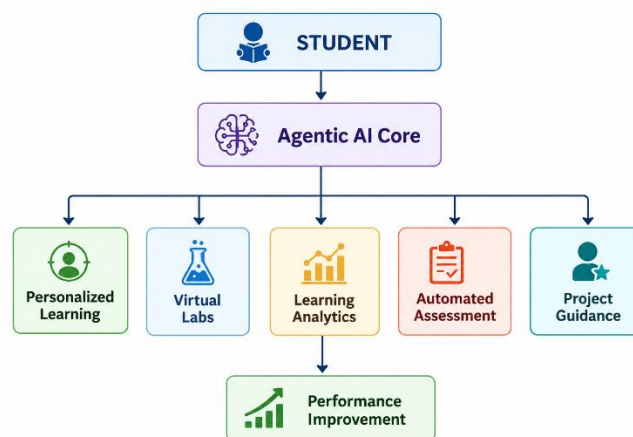


Figure 2: Agentic AI Framework for EE Education

Furthermore, Agentic AI supports instructors by automating routine tasks such as grading, quiz generation, attendance analysis, and performance tracking. This allows faculty members to focus more on mentoring and innovative teaching practices. Although challenges related to data privacy, ethics, and system reliability exist, Agentic AI has significant potential to improve student engagement, learning outcomes, and practical skill development. Therefore, as shown in Figure 2, Agentic AI is emerging as a powerful technology for creating smart, personalized, and effective Electrical Engineering learning environments.

Comparison of Traditional and Agentic AI Learning

Parameter	Traditional Education	Agentic AI Education
Learning Pace	Fixed	Adaptive
Feedback	Delayed	Real-Time
Assessment	Periodic	Continuous
Laboratory Support	Instructor Dependent	AI Assisted
Personalization	Low	High
Student Engagement	Moderate	High
Learning Analytics	Limited	Extensive
Skill Development	Uniform	Individualized

- Approximately 75% of higher education institutions worldwide are exploring or implementing Artificial Intelligence tools to support teaching, learning, and administration.
- Studies indicate that AI-powered personalized learning systems can improve student performance by 15–35% compared to traditional instructional approaches.
- According to industry reports, the global AI in Education market is expected to exceed USD 30 billion by 2030, growing at a Compound Annual Growth Rate (CAGR) of over 35%.
- More than 60% of engineering students report that AI-based tutoring systems help them better understand complex technical concepts and improve problem-solving skills.
- Educational institutions adopting intelligent tutoring systems have observed up to 40% reduction in grading and assessment workload for instructors.
- Virtual laboratories and simulation-based learning environments have been shown to increase practical skill acquisition by 20–30% in STEM disciplines.
- Learning analytics platforms can identify at-risk students with an accuracy of 80–90%, enabling early intervention and improved retention rates.
- Surveys conducted among university faculty indicate that 70% of educators believe AI technologies will significantly influence engineering education within the next five years.
- Recent studies suggest that students using adaptive learning platforms spend 25–30% less time achieving the same learning outcomes compared to conventional learning methods.
- Agentic AI systems integrated with simulation tools such as MATLAB/Simulink and virtual laboratories can provide 24×7 personalized support, enabling self-paced and competency-based learning.

Table : Current Trends and Statistics in AI-Enabled Engineering Education

Metric	Value
Universities adopting AI tools	75%
Improvement in student performance	15–35%
Reduction in faculty grading workload	Up to 40%
Increase in practical skill acquisition	20–30%
Accuracy in identifying at-risk students	80–90%
Faculty expecting major AI impact by 2030	70%
Reduction in learning time	25–30%
AI in Education Market by 2030	USD 30+ Billion

AI in Education Statistics



The adoption of Artificial Intelligence (AI) in higher education has grown significantly in recent years, particularly in engineering disciplines that require personalized learning, simulation-based experimentation, and continuous assessment. Studies indicate that nearly 75% of universities are exploring or implementing AI-powered educational tools to enhance teaching and learning processes. AI-enabled personalized learning systems have demonstrated improvements in student performance ranging from 15% to 35% by providing adaptive content, individualized feedback, and intelligent tutoring support.

Furthermore, AI-assisted assessment systems have reduced faculty grading and evaluation workload by up to 40%, allowing instructors to focus more on mentoring, curriculum development, and research activities. The integration of virtual laboratories, digital twins, and simulation platforms has contributed to a 20–30% increase in practical skill acquisition among engineering students. Learning analytics and predictive modeling techniques can identify at-risk students with an accuracy of 80–90%, enabling timely interventions and improving student retention rates.

Faculty perception studies reveal that approximately 70% of educators believe AI technologies will play a transformative role in engineering education by 2030. In addition, adaptive learning platforms have reduced the time required to achieve learning outcomes by nearly 25–30% compared with traditional teaching approaches. The global AI in Education market is projected to exceed USD 30 billion by 2030, reflecting the increasing demand for intelligent, scalable, and personalized educational solutions. These trends highlight the growing importance of Agentic AI in creating learner-centric educational ecosystems capable of enhancing academic performance, practical competency development, and lifelong learning skills in Electrical Engineering education.

III. CONCLUSION

Agentic Artificial Intelligence (Agentic AI) represents a significant advancement in the evolution of educational technologies and has the potential to transform Electrical Engineering education by enabling intelligent, adaptive, and learner-centric educational environments. Unlike traditional teaching approaches, Agentic AI systems can autonomously analyze learner needs, personalize instructional content, provide real-time feedback, support virtual experimentation, and continuously monitor academic progress. These capabilities are particularly valuable in Electrical Engineering, where conceptual understanding, simulation-based learning, laboratory practice, and problem-solving skills are essential for student success.

The review highlights the growing role of Agentic AI in intelligent tutoring systems, virtual laboratories, automated assessment, learning analytics, and project-based learning. The integration of Agentic AI with engineering tools such as MATLAB/Simulink, circuit simulators, and learning management systems offers opportunities to enhance student engagement, improve learning outcomes, and develop industry-relevant

competencies. Furthermore, the use of predictive analytics and adaptive learning pathways can support early identification of learning difficulties and promote personalized educational experiences.

Despite its numerous advantages, successful implementation of Agentic AI requires careful consideration of challenges related to data privacy, ethical governance, system reliability, explainability, and faculty readiness. Human oversight and institutional support remain essential to ensure responsible and effective deployment. As AI technologies continue to evolve, Agentic AI is expected to play a pivotal role in shaping the future of Electrical Engineering education by fostering competency-based learning, lifelong learning skills, and enhanced educational accessibility. The adoption of Agentic AI-driven educational ecosystems can ultimately contribute to producing highly skilled, innovative, and industry-ready electrical engineers capable of meeting the demands of rapidly evolving technological landscapes.

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