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Effects of IoT–PLC-Based Smart-Industry Learning Model on Problem-Solving and Critical Thinking Skills of Electrical Engineering Students

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Abstract

This study examines the effect of an IoT–PLC-based Smart-Industry learning model on students' problem-solving and critical thinking skills in electrical engineering education. However, empirical studies investigating how IoT–PLC-based instructional models influence higher-order cognitive skills remain limited, particularly in vocational and electrical engineering education contexts. Despite the increasing integration of Industry 4.0 technologies in education, previous studies have primarily focused on technical skill development and often lack empirically validated pedagogical frameworks. The study employed a quantitative quasi-experimental design with a pretest–posttest control group, involving an experimental group taught through the IoT–PLC-based Smart-Industry learning model and a control group taught through conventional instruction. A total of 60 undergraduate students were selected through cluster sampling and assigned to experimental and control groups. Data were collected using validated instruments, with reliability confirmed by Cronbach's alpha coefficients above 0.70. The results indicate that the experimental group achieved significantly higher improvements than the control group ($p < 0.05$), with large effect sizes observed for both problem-solving ($d = 1.45$) and critical thinking ($d = 1.39$). These findings suggest that an IoT–PLC-based Smart-Industry learning model may enhance higher-order cognitive skills, particularly problem-solving and critical thinking, within the specific context of electrical engineering education.

I. INTRODUCTION

This study introduces an IoT–PLC-based Smart-Industry learning model as a pedagogically structured approach for enhancing problem-solving and critical thinking skills among electrical engineering students. Unlike conventional instructional approaches that primarily emphasize procedural knowledge and isolated technical competencies, this model integrates real-time data interaction, automation systems, and project-based learning into a coherent instructional framework. Within this approach, IoT–PLC technologies function as cognitive enablers that

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support students' engagement in higher-order thinking processes. Through interaction with dynamic industrial systems, students analyze real-time data, interpret system behavior, identify operational problems, and construct adaptive solutions. This study therefore contributes to repositioning the role of technology in engineering education from a supportive tool toward a structured medium for cognitive development.

The emergence of Industry 4.0 has significantly transformed modern industrial systems through the integration of cyber-physical systems, artificial intelligence, and interconnected technologies, including the Internet of Things (IoT). These technological advancements have altered the competency demands placed on engineering graduates in contemporary industries. The focus is no longer limited to routine technical operations but increasingly emphasizes higher-order thinking abilities, especially problem-solving and critical thinking skills (Asad & Malik, 2024; Mourtzis et al., 2022). In industrial environments, engineers are expected to analyze real-time information, identify system irregularities, and respond effectively to dynamic operational conditions (Long et al., 2025; Soori et al., 2026). Such demands require graduates to possess not only technical expertise but also strong analytical and decision-making capabilities. Therefore, engineering education must move beyond conventional knowledge delivery and prioritize the development of reasoning, innovation, and adaptive thinking skills (Oyetade et al., 2025).

Despite these evolving demands, current practices in engineering education particularly in electrical engineering remain largely dominated by traditional, instructor-centered approaches. Learning activities are often structured as step-by-step laboratory exercises, where students follow predefined instructions with limited opportunities for inquiry or independent reasoning (Nazionale, 2025). While such approaches are effective for developing foundational technical skills, they often fail to cultivate the ability to address ill-structured and real-world problems. As a result, students tend to develop fragmented understanding and experience difficulties when required to analyze complex systems or make informed decisions (Geirsdotter et al., 2025; Savaengkan & Chaijaroen, 2025). This mismatch between industrial expectations and educational practices highlights the urgent need for more student-centered and cognitively engaging instructional models (Tan et al., 2025).

Recent advancements in technology-based learning have promoted the adoption of Industry 4.0 technologies, especially the Internet of Things (IoT) and Programmable Logic Controllers (PLC), within engineering education. The integration of these technologies supports the creation of learning environments that are more interactive and aligned with industrial practices. IoT and PLC technologies enable real-time monitoring, automated system control, and data-driven communication processes, making learning activities more authentic and immersive (Hendrawati et al., 2025; Wei, 2025). By utilizing IoT–PLC systems, students can simulate industrial operations and observe system performance dynamically. Students can also interact directly with real-time industrial data to better understand system behavior and operational processes (Joko et al., 2023; Ortiz et al., 2025). These learning experiences provide valuable opportunities for developing competencies related to system integration, troubleshooting, and optimization, which are highly relevant in modern industrial environments.

However, despite the growing implementation of IoT–PLC technologies in educational settings, many existing studies still emphasize a predominantly techno-centric approach. Previous research has largely concentrated on technical competencies, including programming skills, system configuration, and device integration, while relatively limited attention has been directed toward the development of higher-order cognitive skills such as problem-solving and critical thinking (Qazi & Pachler, 2025). Consequently, technology is frequently utilized only as a supporting instructional tool within the learning process, and its role as a facilitator of cognitive development is often overlooked in technology-integrated learning environments. This limitation reduces the effectiveness of IoT–PLC-based learning in promoting deeper conceptual understanding, analytical reasoning, and informed decision-making abilities. Furthermore, empirical evidence from authentic educational settings remains scarce, especially studies employing quasi-experimental designs that compare learning outcomes between experimental and control groups. As a result, there remains a lack of a pedagogically structured and empirically validated instructional model that explicitly links IoT–PLC integration with the development of multiple higher-order thinking skills.

From a theoretical standpoint, higher-order thinking skills are closely associated with constructivist and experiential learning theories, which emphasize the active construction of knowledge through meaningful experiences in real-world contexts (Hanisyah & Winarko, 2023; Mir & Alam, 2025). These theories suggest that students learn more effectively when they are actively involved in authentic learning activities. Learning environments that replicate real situations are considered effective in enhancing analytical reasoning, evaluation, and reflective thinking abilities (Weng et al., 2024; Zulkarnaen et al., 2025). Furthermore, instructional models such as problem-based learning and project-based learning are widely acknowledged as effective approaches for developing problem-solving and critical thinking skills (Khosravi et al., 2022). These approaches encourage students to engage with real problems and apply knowledge in practical situations. Therefore, the integration of IoT–PLC technologies should be supported by a well-structured pedagogical framework to ensure that technology integration contributes meaningfully to students’ cognitive development.

To address this gap, this study proposes a Smart-Industry learning model based on IoT–PLC that integrates industrial technologies within a contextual and project-based learning environment. The model is designed to facilitate students in identifying problems, analyzing system behavior, designing solutions, and evaluating outcomes through real-time system interaction. By embedding technology within a structured pedagogical approach, this model aims to promote deeper engagement in higher-order thinking processes and support meaningful learning experiences. The novelty of this study lies in three key aspects. First, it integrates IoT–PLC technologies within a clearly defined pedagogical framework that emphasizes cognitive development rather than mere technical skill acquisition. Second, it simultaneously examines two essential higher-order thinking skills problem-solving and critical thinking within a single instructional model, addressing the limitation of prior studies that tend to focus on only one cognitive outcome. Third, the study provides empirical validation through a quasi-experimental pretest–posttest control group design, thereby strengthening methodological rigor and addressing the lack of experimental evidence in existing research.

Consequently, in this study, the researcher intends to investigate the influence of the proposed Smart-Industry learning model based on IoT and PLCs on problem-solving and critical thinking skills of electrical engineering students. In addition, another objective of this study will be to provide empirical proof for the effectiveness of an instruction process designed through the use of technology. This study uses this technology-enhanced instructional strategy to evaluate its ability to develop several high-level cognitive skills simultaneously. The significance of the research does not lie merely in the use of the technological tool, but rather in investigating how pedagogically sound instruction can assist in developing the necessary cognitive skills.

II. LITERATURE

The rapid evolution of Industry 4.0 technologies has significantly reshaped engineering education by emphasizing the integration of digital and automation systems. Educational institutions are increasingly adopting smart-industry-based learning models to align with industrial requirements. These models incorporate advanced technologies such as the Internet of Things (IoT) and Programmable Logic Controllers (PLC) to create authentic learning environments. While prior studies suggest that such integration contributes to the development of higher-order thinking skills, particularly problem-solving and critical thinking (Tsipianitis et al., 2025), much of the existing literature remains largely descriptive and lacks critical examination of how these skills are systematically developed within instructional frameworks.

Smart-industry learning refers to an educational approach that simulates real industrial ecosystems by integrating cyber-physical systems, automation, and data-driven technologies into the learning process. This approach is widely recognized for enhancing student engagement and learning effectiveness (Hu et al., 2026). However, previous research often emphasizes experiential exposure and engagement without sufficiently analyzing whether such environments explicitly foster cognitive processes such as analysis, evaluation, and reflective thinking. As a result, the relationship between smart-industry environments and higher-order cognitive development remains insufficiently conceptualized.

The Internet of Things (IoT) plays a crucial role in enabling connectivity and real-time data exchange within smart learning environments. Through IoT, devices communicate seamlessly, allowing students to monitor and control systems remotely, thereby enhancing interactive learning experiences. Studies have shown that IoT-based learning can improve analytical and decision-making abilities (Ji & Wu, 2025). Nevertheless, these studies tend to emphasize technological interaction rather than providing a structured explanation of how such interactions lead to measurable improvements in higher-order thinking skills, particularly critical thinking.

In engineering education, IoT also facilitates data-driven learning processes where students analyze real-time data generated from sensors and devices. This approach encourages interpretation, evaluation, and decision-making based on empirical evidence (Demissie et al., 2022). However, many studies assume that exposure to data inherently leads to improved cognitive abilities, without providing empirical validation or clearly defined measurement frameworks. This reveals a gap in linking technological interaction with explicit cognitive outcomes.

Programmable Logic Controllers (PLC) are widely used in industrial automation and play a central role in engineering training. PLC-based learning enables students to design, implement, and troubleshoot automated control systems, thereby strengthening technical competencies (Widinata & Irawan, 2025). While these studies report improvements in logical reasoning and technical problem-solving, they often conceptualize problem-solving narrowly as a technical skill rather than as a higher-order cognitive process involving analysis, evaluation, and reflection.

The integration of PLC into educational contexts allows students to simulate industrial processes and experiment with various programming scenarios. This experiential approach supports conceptual understanding and prepares students for industrial challenges. However, prior studies frequently lack a clearly articulated pedagogical structure explaining how these activities are intentionally designed to develop higher-order thinking skills. Consequently, PLC-based learning is often implemented as a technical training tool rather than as a cognitively oriented instructional model.

The combination of IoT and PLC technologies creates a powerful smart-industry learning environment that bridges theoretical knowledge and practical application. This integration supports interdisciplinary learning and enhances students' readiness for industrial contexts (Maya Ortiz, 2025). Despite its potential, existing studies tend to emphasize employability and technical readiness, with limited attention to how such integration fosters higher-order thinking within a structured pedagogical framework.

Problem-solving is widely recognized as a fundamental competency in engineering education. Smart-industry learning environments provide opportunities for students to engage with real-world problems and apply systematic reasoning (Lu & Xie, 2024). However, prior studies often conceptualize problem-solving in procedural terms, focusing on technical execution rather than on complex, ill-structured problem-solving that requires deeper cognitive engagement.

Similarly, critical thinking is an essential competency in the context of Industry 4.0, where engineers must evaluate data, assess system performance, and make informed decisions (Marini et al., 2026). While IoT–PLC environments provide opportunities for such activities, many studies assume that technology use inherently promotes critical thinking without explicitly designing learning activities that target these cognitive processes. As a result, critical thinking development is often incidental rather than systematically facilitated.

Instructional approaches such as problem-based learning (PBL) and project-based learning (PjBL) are frequently integrated into smart-industry education to promote student-centered learning and real-world problem-solving. These approaches have been shown to improve engagement and learning outcomes (De Bruijn-Smolders & Prinsen, 2024). However, existing studies rarely examine how these pedagogical approaches interact with IoT–PLC technologies to specifically enhance higher-order thinking skills. This indicates a lack of integration between pedagogical design and technological implementation.

Similarly, competency-based education is supported by smart-industry learning models, emphasizing the development of skills relevant to the workforce (Yi & Park, 2024). While this approach improves students' readiness for professional careers, it often prioritizes measurable performance outcomes over deeper cognitive processes, thereby limiting its contribution to the development of critical thinking and problem-solving skills.

Despite the recognized benefits of IoT–PLC-based learning, several challenges remain, including high implementation costs, limited instructor expertise, and curriculum constraints (Abdullah & Al-Ahmari, 2025). While these studies highlight practical barriers, they often overlook the pedagogical challenges associated with designing learning environments that effectively integrate technology and cognitive development.

A critical review of previous studies indicates that IoT- and PLC-based learning has commonly been evaluated through technical performance indicators, while cognitive outcomes such as problem-solving and critical thinking have received less empirical attention. Moreover, many studies remain descriptive, exploratory, or case-based, limiting their ability to establish stronger causal claims regarding instructional effectiveness. In addition, existing research often lacks a clear alignment between technology integration and pedagogical strategies, resulting in fragmented implementations where technology supports activity but does not explicitly drive cognitive development. This suggests that the current body of literature has not yet fully addressed how IoT–PLC-based learning can be systematically designed and empirically validated to enhance higher-order thinking skills.

Beyond conceptual limitations, a significant methodological gap is evident in prior research. Most studies on IoT–PLC-based learning rely on descriptive, exploratory, or case-study approaches, which limit their ability to establish causal relationships between instructional interventions and learning outcomes. Few studies employ rigorous experimental or quasi-experimental designs that allow for comparison between control and experimental groups. As a result, the effectiveness of technology-integrated learning models in improving higher-order cognitive skills remains insufficiently validated.

Furthermore, previous research rarely examines multiple cognitive variables simultaneously, particularly the combined development of problem-solving and critical thinking within a single instructional framework. The absence of such comprehensive and methodologically rigorous studies highlights the need for research designs that provide stronger empirical evidence. Therefore, this study addresses these limitations by employing a quasi-experimental pretest–posttest control group design to evaluate the effectiveness of the IoT–PLC-based Smart-Industry learning model in enhancing students’ higher-order thinking skills.

III. RESEARCH METHOD

In this research, a quantitative methodological strategy was applied through a quasi-experimental design of pretest-posttest control group to study the influence of an IoT–PLC-based Smart-Industry learning framework on students' problem solving and critical thinking skills. Quasi-experimental research was chosen due to the fact that it was conducted under real-life conditions in an educational context, and hence it was not possible to randomly assign individual subjects. Random assignments of participants cannot be easily done in the case of higher education, particularly because of bureaucratic considerations and requirements for retaining the intactness of existing classes.

Compared with purely observational designs, the pretest–posttest control group design provides stronger evidence of instructional effectiveness because it enables the researcher to examine baseline equivalence, measure learning gains, and compare post-intervention differences between groups. By incorporating both control and experimental groups, as well as pretest and posttest measurements, this design allows for a more robust evaluation of the causal impact of the instructional intervention. Although it does not achieve the full control of a true experimental design, the inclusion of baseline comparison and controlled instructional conditions enhances internal validity while maintaining ecological validity in real classroom settings.

The pretest–posttest control group design was considered particularly appropriate for this study as it allows for a systematic assessment of learning gains in problem-solving and critical thinking skills. The pretest was administered to establish baseline equivalence between the experimental and control groups, ensuring that any observed differences in the posttest could be attributed to the intervention rather than to initial disparities. This is particularly important when measuring higher-order cognitive skills, which often vary among students prior to instruction.

Furthermore, the inclusion of both pretest and posttest measurements enables the analysis of changes over time within each group, as well as comparisons between groups. This design allows the researcher to evaluate not only whether learning occurred, but also the extent of improvement attributable to the intervention. By comparing gain scores between the experimental and control groups, the effectiveness of the IoT–PLC-based Smart-Industry learning model can be assessed more accurately.

The participants of this study were 60 undergraduate students enrolled in an Electrical Engineering Education program. The participants were divided into two groups experimental and control using cluster sampling, with each group consisting of 30 students. Cluster sampling was employed to maintain the integrity of existing classroom groupings and to avoid disruption to the academic schedule.

To ensure comparability between groups, pretest data were analyzed prior to the intervention. The results indicated no statistically significant difference in initial problem-solving and critical thinking abilities between the experimental and control groups, thereby confirming baseline equivalence. Establishing this equivalence is essential in quasi-experimental research to strengthen internal validity and support causal interpretation.

The intervention was conducted over a period of six to eight weeks. The experimental group participated in the Smart-Industry learning model integrating IoT–PLC within a project-based learning framework. The learning process involved several stages, including problem identification, system design, implementation, testing, and evaluation of automation systems. Students engaged in real-time data analysis, system troubleshooting, and decision-making processes, requiring the active application of problem-solving and critical thinking skills.

In contrast, the control group received conventional instruction consisting of lecture-based teaching and structured laboratory exercises with predefined procedures. This approach reflects typical instructional practices in engineering education, where students follow step-by-step guidelines with limited opportunities for independent inquiry. The comparison between these two instructional approaches enables a clear evaluation of the added value of the Smart-Industry learning model.

Data were collected using validated instruments designed to measure problem-solving and critical thinking skills. The problem-solving instrument assessed students’ ability to identify problems, develop solution strategies, and implement effective solutions. The critical thinking instrument measured key dimensions such as analysis, evaluation, inference, and logical reasoning.

Content validity was established through expert judgment to ensure alignment between the instruments and the intended learning outcomes (Maryani et al., 2022). Reliability analysis using Cronbach’s alpha yielded coefficients above 0.70, indicating acceptable internal consistency. These procedures ensured that the instruments provided accurate and reliable assessments of students’ cognitive skills.

The research procedure consisted of three main stages: pretest, intervention, and posttest. Both groups completed the same pretest prior to the intervention to establish baseline equivalence. Following the intervention period, a posttest was administered under standardized conditions to ensure consistency.

Data analysis included both descriptive and inferential statistical techniques. Descriptive statistics were used to summarize students’ performance, while inferential statistics were employed to test the research hypotheses. Prior to hypothesis testing, normality and homogeneity tests were conducted to ensure that the data met the assumptions required for parametric analysis. An independent samples t-test was used to determine significant differences between the experimental and control groups at a significance level of 0.05. Additionally, N-Gain analysis was conducted to evaluate the effectiveness of the intervention in improving students’ problem-solving and critical thinking skills.

The ethical issues of the research were extensively covered in the research process. The research was fully voluntary, and all participants had been briefed beforehand about the purpose and expected outcome of the research. They were all given a choice to participate and were not coerced in any way.

The privacy of all participants was ensured by ensuring complete anonymity of all data collected. Data was used strictly for research purpose only and stored in a protected database that could be accessed only by authorized persons. Moreover, it was ensured that none of the participants was put into any sort of jeopardy because of the research. The same teaching methodology based on curriculum was used for both control and experimental groups.

IV. RESULTS AND DISCUSSION

This study examined the effect of the IoT–PLC-based Smart-Industry learning model on students' problem-solving and critical thinking skills. Descriptive statistics, including mean and standard deviation, are presented in Table 1.

Table 1. Descriptive Statistics

Group	PS Pretest (M±SD)	PS Posttest (M±SD)	CT Pretest (M±SD)	CT Posttest (M±SD)
Experimental	62.2 ± 6.5	84.3 ± 5.8	60.3 ± 6.2	82.2 ± 5.6
Control	61.2 ± 6.7	70.3 ± 6.1	60.1 ± 6.4	69.9 ± 6.0

Table 1 shows that the pretest mean scores of both groups are relatively comparable for problem-solving and critical thinking. The posttest mean scores of the experimental group are higher than those of the control group. To evaluate learning improvement, N-Gain analysis was conducted, as presented in Table 2.

Table 2. N-Gain Results

Group	Problem Solving	Category	Critical Thinking	Category
Experimental	0.58	Moderate High	0.55	Moderate
Control	0.24	Low	0.21	Low

Table 2 presents the N-Gain values for both groups, indicating different levels of improvement in problem-solving and critical thinking skills. Prior to hypothesis testing, normality and homogeneity tests confirmed that the data met the assumptions for parametric analysis. The results of the independent samples t-test and effect size analysis are presented in Table 3.

Table 3. Independet Samples t-Test and Effect Size

Variable	t-value	p-value	Effect Size (Cohen's d)
Problem Solving	7.85	0.000	1.45 (large)
Critical Thinking	7.62	0.000	1.39 (large)

Table 3 shows that the p-values for both variables are below 0.05, indicating statistically significant differences between the experimental and control groups. The effect size values indicate a large magnitude of difference between groups.

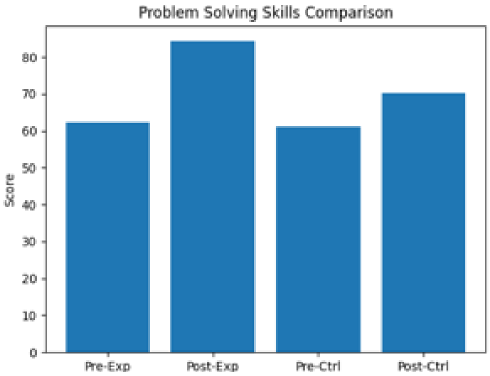

Figure 1. Comparison of Problem-Solving Skills Between Experimental and Control Groups

Figure 1 presents the comparison of pretest and posttest scores of problem-solving skills between the experimental and control groups. Both groups show similar pretest scores, while the posttest score of the experimental group is higher than that of the control group.

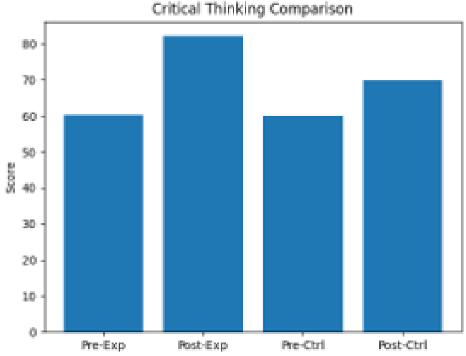

Figure 2. Comparison of Critical Thinking Skills Between Experimental and Control Groups

Figure 2 presents the comparison of pretest and posttest scores of critical thinking skills between the experimental and control groups. Both groups have comparable pretest scores, while the experimental group demonstrates higher posttest scores than the control group.

The findings of this study demonstrate that the IoT–PLC-based Smart-Industry learning model has a substantial effect on students' problem-solving and critical thinking skills. The statistical results indicate not only significant differences between the experimental and control groups ($p < 0.05$), but also large effect sizes (Cohen's $d > 1.3$), suggesting that the magnitude of the intervention effect is strong. This indicates that the observed improvements are not only statistically meaningful but also practically significant in enhancing students' higher-order cognitive abilities.

The higher posttest scores and N-Gain values observed in the experimental group further support the effectiveness of the Smart-Industry learning model. The moderate N-Gain values (0.55–0.58) indicate that the intervention produced meaningful learning improvements, while the low N-Gain values in the control group suggest limited progress under conventional instruction. These results highlight that the integration of IoT–PLC technologies within a structured pedagogical framework provides a more effective learning environment for developing higher-order thinking skills.

From a theoretical perspective, these findings are consistent with constructivist learning theory, which posits that knowledge is actively constructed through meaningful interaction with real-world contexts (Mir & Alam, 2025). The large effect sizes observed in this study suggest that learning environments incorporating real-time data interaction and system-based problem-solving can significantly enhance cognitive engagement. The Smart-Industry learning model facilitates active knowledge construction by enabling students to interact with authentic industrial systems, thereby promoting deeper understanding and reflective thinking. This supports previous studies indicating that experiential and contextual learning environments improve higher-order cognitive skills (Weng et al., 2024).

In terms of problem-solving skills, the results indicate that students in the experimental group developed stronger abilities to identify, analyze, and resolve complex problems. The large effect size ($d = 1.45$) suggests that the Smart-Industry learning model substantially enhances students' capacity for systematic and analytical problem-solving. This finding aligns with prior research demonstrating that project-based and technology-enhanced learning approaches can improve students' ability to address complex, real-world problems (Lu & Xie, 2024; Savaengkan &

Chaijaroen, 2025). The iterative learning process embedded in the model—consisting of problem identification, system design, implementation, and evaluation—mirrors real industrial practices and supports the development of structured problem-solving strategies.

Similarly, the improvement in critical thinking skills is supported by a large effect size (d = 1.39), indicating a strong impact of the intervention. The use of IoT–PLC technologies enable students to engage in data analysis, system evaluation, and evidence-based decision-making. These activities correspond to key dimensions of critical thinking, including analysis, evaluation, and inference. The findings are consistent with previous studies showing that technology-integrated learning environments can enhance students’ analytical and evaluative thinking skills (Marini et al., 2026; Yilmaz & Karaoglan, 2023). However, this study extends prior research by demonstrating that such improvements are not merely incidental but can be achieved through a structured instructional model.

Importantly, this study provides evidence for the simultaneous development of both problem-solving and critical thinking skills within a single instructional model. While previous studies often examine these cognitive skills separately (Tsipianitis et al., 2025), the large effect sizes observed across both variables indicate that the Smart-Industry learning model effectively supports multiple dimensions of higher-order thinking. This highlights the importance of integrating pedagogical design with technological tools to achieve comprehensive cognitive outcomes.

Furthermore, the findings reinforce the role of IoT–PLC technologies as cognitive enablers rather than merely instructional tools. The large effect sizes suggest that the effectiveness of technology integration depends on how it is embedded within a pedagogical framework. When technology is aligned with problem-based and project-based learning strategies, it can facilitate deeper cognitive engagement and meaningful learning experiences. This supports the argument that technology should be viewed as an integral component of instructional design rather than as a supplementary resource (Qazi & Pachler, 2025).

Another important contribution of this study lies in its methodological rigor. By employing a quasi-experimental pretest–posttest control group design, this study provides stronger empirical evidence compared to prior research that relies on descriptive or exploratory approaches. The combination of significant results and large effect sizes strengthens the validity of the findings and supports causal interpretation. This directly addresses the methodological gap identified in previous studies regarding the lack of rigorous experimental validation in technology-integrated learning research.

From a theoretical perspective, this study contributes to the literature by providing empirical support for the integration of constructivist pedagogy and Industry 4.0 technologies in fostering higher-order thinking skills. It demonstrates that cognitive development can be enhanced through the combination of authentic learning environments and structured instructional design.

From a practical perspective, the findings suggest that educators should adopt technology-integrated and project-based learning approaches to improve students’ problem-solving and critical thinking skills. Curriculum developers are encouraged to incorporate IoT and PLC technologies into engineering education to better align learning with industrial demands. Additionally, educational institutions should invest in infrastructure and professional development to support the effective implementation of such learning models (Abdullah & Al-Ahmari, 2025).

However, there are some aspects to be considered as well. First, the experiment took place in an educational setting, and a rather small group was used; thus, the results cannot be generalized.

Moreover, the length of the intervention may not have been sufficient to observe long-lasting effects on students.

In conclusion, further research can be suggested to determine how effective Smart-Industry learning is when implemented at various educational levels and in other disciplines. Long-term observations could shed light on the effect of technology integration on children's cognitive development. Moreover, other factors could be considered as well, including motivation, collaboration skills, and more.

V. CONCLUSION

The present study sought to analyze the effects of the Smart-Industry learning model based on IoT and PLC on the problem-solving and critical thinking skills of learners under the field of electrical engineering. From the results of this study, it is evident that application of this model promotes cognitive achievement among learners more than traditional methods of instruction do. This is because of the use of contextualized, project-based learning environment through the utilization of IoT and PLC technology.

In addition, the findings provide more evidence indicating that technology-assisted learning, when complemented with the appropriate pedagogic approach, can successfully support the development of problem-solving and critical thinking skills among students. This is because the Smart-Industry learning model creates an effective learning atmosphere through which learners become actively involved and connect theory with its practical application in terms of Industry 4.0.

Regarding contributions, this research will provide empirical evidence on how effective it is for teachers to utilize IoT-PLC technologies as part of a systematic learning framework in order to improve various levels of critical thinking simultaneously. It makes a contribution to the realm of engineering education as it proves how technology can act as a cognitive tool.

Nevertheless, there are several issues that must be pointed out. The research took place under a particular educational framework, with a relatively small number of subjects being studied. While the results have been rather promising for the educational setting under investigation, it would be erroneous to generalize the outcomes without additional empirical evidence. In order to establish the model's adaptability and reliability, it would be necessary to conduct new experiments, involving bigger sample sizes and various educational frameworks. Moreover, additional research needs to be done to include other variables into consideration, such as students' engagement, motivation, and collaboration abilities.

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VII. SUPPORTING INFORMATION

All relevant information related to the research design, learning intervention, instruments, data analysis procedures, and main findings has been presented within the manuscript. The data used in this study were collected solely for research purposes and handled in accordance with ethical considerations, including participant anonymity and confidentiality. Further information regarding the research procedure may be made available by the corresponding author upon reasonable request, subject to institutional and ethical approval.

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