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The Role Of Simulation Software In Enhancing Practical Skills For Students In Electrical Automation

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Abstract:

The paper evaluates the role of simulation software in improving the practical skills of students of Electrical – Automation and explains the pedagogical mechanism that helps turn "software hours" into "measurable competence". Mixed-methods research with 309 participants (287 students, 22 lecturers) at three campuses (School of Electrical and Electronic Engineering, Hanoi University of Science and Technology; School of Electrical and Electronics, Hanoi University of Industry; University of Industry – Thai Nguyen University). The five core platforms include MATLAB/Simulink, Proteus VSM, Siemens TIA Portal, Beckhoff TwinCAT 3, and Factory I/O. The quantitative block uses a tested scale (Cronbach's α=0.81–0.89), EFA (KMO=0.91; 6 factors; extraction variance 68.4%), CFA (CFI=0.94; TLI=0.92; RMSEA=0.048) and SEM for direct/indirect impact testing; 5,000-sample bootstrap and multi-group analysis (MG-SEM) test for durability and differentiation by school year/campus. Topic-coded qualitative blocks (interviews/observations) to collate results.

The results show that the direct impact is consistent with the pedagogical function of each software: MATLAB/Simulink → modeling skills (β=0.42), Proteus → embedded skills (β=0.37), TIA Portal → PLC skills (β=0.34), TwinCAT → distributed control (β=0.28), Factory I/O → system integration (β=0.26). Three intermediate channels are significant: Active Learning (AL) is the strongest (β_indirect=0.14), followed by interactive learning (0.12) and project-based teaching – PBL (0.10). R^2=0.29–0.47 suggests that simulation is an important lever but still needs support from real labs, mentoring, and appropriate learning organization. MG-SEM confirms measurement invariance (ΔCFI=0.004; ΔRMSEA=0.003) and records year 4 over year 3 in TIA→PLC (+0.08) and Factory I/O→integrated (+0.07). Qualitative data indicate onboarding for the first 2–3 sessions, capstone attached to industrial situations, and mentoring is the key to amplifying the effect.

Keywords: *digital simulation; practical skills; Electrical – Automation; active learning; project teaching; linear structure model.*

1. INTRODUCTION

1.1. Research context

The Electrical and Automation industry is playing a key role in the global industrialization, modernization and digital transformation. The Industrial Revolution 4.0 with key technologies such as artificial intelligence (AI), the Internet of Things (IoT), Big Data, cloud computing, and the Digital Twin model has created fundamental changes in industrial production as well as in technical education. In particular, digital simulation is considered a foundational tool to help students experience practical situations close to reality in a safe, economical and flexible virtual environment (Magana et al., 2018) [1].

Negahban (2024) [2] asserts that the use of simulation in engineering education is the transition from physical experiments to digital simulation environments where learners can interact and verify knowledge. Heradio et al. (2016)[3] emphasize the role of virtual and remote labs in expanding student access, while Ma & Nickerson (2006)[4] argue that the combination of real-world experiments, simulations, and remote labs is all-roundly effective. This trend is becoming increasingly important as Digital Twins are applied in education (Chen et al., 2020) [5].

According to Irfan et al. (2022) [6], simulation systems not only improve the quality of training but also help universities overcome the limitations of facilities. The application of the Kolb learning cycle to the engineering lab has been shown to be effective by Abdulwahed & Nagy (2009)[7] when combined with a simulation tool. Feisel & Rosa (2005)[8] emphasize the pivotal role of the laboratory in the training of engineers, but also affirm that the addition of digital tools is inevitable.

Follow-up studies (Viegas et al., 2018 [9]; Freeman et al., 2014 [10]) point out that active learning – often implemented through simulation software – has helped students significantly increase their academic performance. These results are in line with the direction of international output standards such as CDIO [11] and ABET [12], which value practical skills, design thinking and problem-solving.

1.2. Current situation and challenges in practical training

For many years, Electrical and Automation training programs have relied heavily on physical experiments in the laboratory. Mills & Treagust (2003)[13] and Prince & Felder (2006)[14] argue that this approach, while important, is not sufficient to develop comprehensive competencies. The application of the Project-Based Learning (PBL) approach has been shown to be effective in technical education (Hadim & Esche, 2002) [15]. Vargas et al. (2022) [16] show that when PBL is combined with the Factory I/O simulation tool, students become more proactive and develop better skills.

The current training situation still has many challenges:

1. High investment costs: PLC, robotic, SCADA, and microgrid systems require large funds, which are difficult to feasibility with many training institutions (Irfan et al., 2022) [6].
2. Limited number of equipment: The small number of equipment leads to students not having many opportunities for repeated practice (Heradio et al., 2016) [3].
3. Safety risks: High-voltage systems and industrial robots pose a potential risk to students (Ma & Nickerson, 2006) [4].
4. Lack of flexibility: Physics experiments are difficult to simulate complex, interdisciplinary scenarios (Viegas et al., 2018) [9].

Freeman et al. (2014) [10] demonstrate that the application of active learning significantly increases learning outcomes, with simulation playing a foundational role. This result is consistent with CDIO[11] and ABET[12] recommendations for strengthening practice, soft skills, and systems thinking in engineer training.

1.3. Roles and trends of simulation software application

Matlab/Simulink is the benchmark tool in the teaching of controls, electrical systems, and power electronics. MathWorks (2023) has developed many learning resources (Teaching Controls [17], Simulink for Teaching [18], CTMS [19], Power Electronics [20], Simscape Electrical [21]). The textbooks Ogata (2015)[22], Dorf & Bishop (2017)[23], Boulet (2018)[24], Karris (2012)[25] all integrate simulations, while File Exchange[26] provides a large repository of resources for teaching.

Proteus is commonly used in microcontroller teaching and digital circuit design (Labcenter, 2023 [27][28][29]). Zaraa et al. (2019)[30] demonstrate that Proteus makes microcontroller programming accessible to students. Papers in MDPI Electronics (2021)[31] and research by Silva et al. (2018)[32] show that the combination of Proteus and Arduino is highly effective in teaching.

The Siemens TIA Portal is considered the industry standard in PLC programming. Siemens' training resources (2023)[33][34][35][36] and use cases (2020)[37] have strongly supported education. The S7-1200 kit [38], research at IEEE ETFA (2020)[39] and Springer (2021)[40] confirms the important role of the TIA Portal in education.

TwinCAT 3 is a powerful tool in IEC 61131-3 teaching. Beckhoff (2023) provides a variety of materials (TwinCAT Overview [41], Getting Started [42], eLearning Portal [43], Simulation Manager [44]). Studies (ResearchGate, 2019 [45]; IEEE, 2019–2023 [46]) shows that TwinCAT is suitable for teaching distributed systems and motion control.

Factory I/O (2023)[47][48][49] creates a 3D visual environment for students to simulate a production line. Didactic systems from Festo [50] and Lucas-Nülle [51] are strongly supportive in training. OPC UA (OPC Foundation, 2023) [52], educational application (VDI/VDE, 2019 [53]), Matlab–PLC integration study (2022) [54], Schneider Electric solution [55], and Inductive Automation [56] show the pivotal role of SCADA/OPC UA in engineering education.

Tadeu et al. (2020) [57], Moreschi et al. (2021) [58], García et al. (2019) [59] and Roldán et al. (2019) [60] all affirm the importance of digital twins, SCADA, and virtual commissioning in education. These tools help students experience virtual reality situations, increasing their analytical and operational abilities.

1.4. Research gaps and objectives of the article

Although many studies have focused on numerical simulations, most have delved into only one tool or a specific aspect (Magana et al., 2018 [1]; Zaraa et al., 2019 [30]; Siemens, 2023 [33]). There have not been many comprehensive studies and comprehensive analysis of the impact of multiple simulation platforms in Electrical – Automation training.

2. THEORETICAL BASIS AND RESEARCH OVERVIEW

2.1. Rationale

2.1.1. Concept and role of practical skills in Electrical – Automation engineer training

In the field of technical education, **practical skills** are considered a central factor to help transform theoretical knowledge into professional competencies. According to Magana et al. [1], this skill includes the ability to operate, design, simulate and analyze complex engineering systems. Modern engineers cannot only operate on real devices but need to master digital tools to make optimal decisions and adapt to rapid changes in the context of industry 4.0.

Negahban [2] emphasizes that engineer training needs to shift from relying entirely on physical experiments to leveraging the power of numerical simulation, where students can test their knowledge in a safe and flexible environment. Heradio et al. [3] argue that combining a physical lab with a virtual and remote lab is an effective path to sustainable practice skill formation. Ma & Nickerson [4] added that the balance between hands-on experiences, simulations, and remote labs makes for a comprehensive platform for students. Recently, Chen et al. [5] expanded on this view by asserting that practicing on digital twins is also a new form of hands-on skill, preparing students to work in digital industrial systems.

According to Irfan et al. [6], practicing in a simulated environment offers many advantages: students can approach diverse situations, minimize safety risks, save equipment costs, and easily iterate multiple times. This is in line with the modern approach to competency-based training, which emphasizes the adaptation of learners in a rapidly changing environment.

2.1.2. Teaching theory related to simulation application

The application of simulation in education can be explained based on a variety of pedagogical theories. One prominent theoretical framework is **the Kolb experiential learning cycle**. Abdulwahed & Nagy [7] demonstrated that combining simulation with steps in the cycle (experience – reflect – generalize – apply) improves acquisition efficiency.

Feisel & Rosa [8] emphasize that the traditional laboratory remains the core, but the addition of simulation expands the scope, increases reproducibility and reduces dependence on facilities. Viegas et al. [9] argue that virtual and remote labs encourage collaborative learning, and Freeman et al. [10] demonstrate that simulation is a powerful tool for implementing active learning, which significantly increases learning outcomes in STEM disciplines.

International output standards such as **CDIO** [11] and **ABET** [12] both place great importance on the formation of practical skills, design thinking and problem-solving. All of these competencies can be effectively developed through the simulation tool. Mills & Treagust [13] propose a **Project-Based Learning (PBL) approach**, in which simulation plays a core role in creating the context of practice. Prince & Felder [14] asserts that when students are explored through simulation, creativity and self-learning are increased. Hadim & Esche [15] show that PBL incorporates simulation that promotes initiative, while Vargas et al. [16] demonstrate that Factory I/O in competency-based training helps students develop practical skills.

2.1.3. Simulation tools in technical training

In the context of Industry 4.0, many simulation software has become the standard in Electrical – Automation training:

1. **MATLAB/Simulink**: According to MathWorks [17–21], this is the standard tool for teaching control and electrical systems. Ogata[22], Dorf & Bishop[23], Boulet[24], Karris[25] all consider Simulink as the nucleus of training. The File Exchange community[26] provides an extensive repository of resources, supporting faculty and students.
2. **Proteus**: Labcenter [27–29] introduces the Proteus Design Suite and VSM as comprehensive solutions in microcontroller training. Zaraa et al. [30] and Silva et al. [32] assert that Proteus incorporates Arduino to improve teaching efficiency. The work on MDPI Electronics [31] also highlights the role of Proteus in digital circuit training.
3. **Siemens TIA Portal & PLCSIM Advanced**: Siemens documentation [33–36] shows that the TIA Portal is the industry standard for PLC training. Use cases [37], IEEE ETFA [39] and Springer [40] study all confirm the practicality of this tool.
4. **Beckhoff TwinCAT 3**: Documents from Beckhoff [41–44] and recent research [45,46] indicate that TwinCAT is suitable in distributed control teaching, IEC 61131-3 programming, and real-time systems.
5. **Factory I/O & SCADA mini**: According to Factory I/O [47–49], this is a 3D visual environment for the production line. Didactic systems from Festo [50] and Lucas-Nülle [51] are a powerful complement to training.
6. **OPC UA and SCADA:** The OPC Foundation [52], VDI/VDE [53] and studies [54–56] confirm that OPC UA is an industrial connectivity standard that plays a key role in training.

- **Digital Twins and Virtual Commissioning**: Tadeu et al. [57], Moreschi et al. [58], García et al. [59] and Roldán et al. [60] emphasize the role of digital twins in helping students experience virtual industrial situations and develop analytical and operational skills.

2.1.4. Simulation-based practice competency framework

Based on theories and simulation tools, it is possible to build a **practical competency framework** for students in Electrical – Automation including:

1. Modeling Capacity (MATLAB/Simulink) [17–26].
2. Ability to design circuits and embedded systems (Proteus) [27–32].
3. Ability to program and operate PLC (TIA Portal) [33–40].
4. Distributed Control Capacity (TwinCAT) [41–46].
5. System integration capabilities (Factory I/O, SCADA mini) [47–51].
6. Digital Industry Interaction Capacity (OPC UA, Digital Twin) [52–60].

This framework not only reflects the progress of development from basic to advanced, but also ensures a close cohesion between academic knowledge and industrial practice.

2.2. Research overview

2.2.1. Research on Proteus and Embedded Systems

Labcenter [27–29] introduced Proteus as a powerful tool for electronic circuit design and testing. Zaraa et al. [30] show that Proteus gives students a quick access to microcontroller programming. Silva et al. [32] combined Proteus with Arduino to create virtual labs, save costs, and expand training capabilities. Papers in MDPI Electronics [31] confirm the effectiveness of the application of Proteus in teaching digital circuits.

2.2.2. Research on Siemens TIA Portal and PLC training

Siemens [33–36] provides comprehensive resources for training. Use cases [37] demonstrate the applicability of the TIA Portal in virtual commissioning. The S7-1200 kit [38] is widely used in training, and research at IEEE ETFA [39] and Springer [40] shows that students have faster access to modern manufacturing technology thanks to this tool.

2.2.3. Research on Beckhoff TwinCAT and distributed control

Beckhoff [41–44] built a comprehensive training ecosystem. ResearchGate [45] indicates that TwinCAT helps teach PLC programming and motion control. IEEE works[46] from 2019–2023 highlight TwinCAT's alignment with distributed systems training and industry 4.0.

2.2.4. Research on Factory I/O and visualization training

Factory I/O [47–49] creates a 3D visual learning environment, allowing students to simulate a production line. Vargas et al. [16] demonstrate that Factory I/O enhances system integration skills. Systems from Festo [50] and Lucas-Nülle [51] also make an important contribution to automation training.

2.2.5. Trends of OPC UA, SCADA in training

OPC UA is the global standard for industrial connectivity [52]. VDI/VDE [53] affirms that the application of OPC UA in education helps students better understand the industrial communication standard. ResearchGate [54] demonstrates the integration of Matlab with PLCs via OPC UA in microgrid management. Schneider Electric[55] and Inductive Automation[56] also offer state-of-the-art SCADA solutions for education.

2.2.6. Research on Digital Twin and Virtual Commissioning

Tadeu et al. [57] showed that teaching PLC by simulation is both effective and cost-effective. Moreschi et al. [58] assert that virtual labs combined with virtual commissioning help students quickly grasp the production process. García et al. [59] demonstrate SCADA-based learning enhances supervisory skills, while Roldán et al. [60] consider the Digital Twin to be an important step forward in automation and robotics training.

2.2.7. Research gaps

Most studies have focused on an individual tool or aspect, e.g. Proteus [30–32], TIA Portal [33–40], TwinCAT [41–46], Factory I/O [47–51] or Digital Twin [57–60]. There have not been many cross-platform integration works to assess the comprehensive impact on practical skills. This gap opens up research opportunities to build an overall analytical framework, affirming the central role of digital simulation in the training of Electrical and Automation engineers.

3. RESEARCH METHODS

3.1. Research design

This study uses mixed-methods, a combination of quantitative and qualitative. The choice of the mixed design stemmed from two main reasons. Firstly, the impact of simulation software in Electrical – Automation training has both a "hard" aspect (measurable by skill scales, linear structure models) and a "soft" aspect (attitudes, interests, learning behaviors), so an individual method alone will not be enough to reflect comprehensively [1], [6]. Secondly, the learning environment with simulations is often associated with specific classroom contexts, so cross-checking between quantitative results and qualitative evidence improves the reliability of conclusions [7].

In the quantitative sector, the study applied a questionnaire survey with a scale that has been tested according to international standards CDIO [11] and ABET [12]. Analyses include Cronbach's Alpha, discovery factor analysis (EFA), confirmation factor analysis (CFA), and linear structure modeling (SEM) with a bootstrap of 5,000 samples. In addition, a multi-group analysis (MG-SEM) was implemented to check the sustainability of the model.

In the qualitative block, the study conducted semi-structured interviews and classroom observations. These data are thematically coded, in order to explain how simulations affect practical skills. This hybrid approach is consistent with the recommendations of Abdulwahed & Nagy[7] and Feisel & Rosa[8] for the application of the Kolb learning cycle in an engineering laboratory context.

3.2. Conceptual models and research hypotheses

The research model is constructed in three layers of variables:

1. **Independent Variable** – Simulation Platform Group: MATLAB/Simulink, Proteus VSM, Siemens TIA Portal/PLCSIM, Beckhoff TwinCAT 3, Factory I/O.
2. **Intermediate Variable** – Pedagogical Architecture: Active Learning (AL), Learning Interaction, and Project-Based Learning (PBL).
3. **Dependent Variables** – Hands-on skill sets: modeling, embedded design, PLC programming, distributed control, system integration, and digital industrial interaction.

From this model, the study offers two main clusters of hypotheses:

1. H1–H5: The direct impact of each simulation platform on the corresponding skill group (positive and statistically significant expectations).
2. H6–H8: The mediating role of AL, learning interaction, and PBL in the relationship between simulation and skills.

In addition, the study examined the difference between **the school year** (year 3 and year 4) and **proficiency** (high vs medium self-report), in order to assess the sustainability of the model under different conditions.

3.3. Measurement tools

3.3.1. Scale construction

The scale was developed based on the CDIO [11] and ABET [12] frameworks, along with materials related to numerical simulation in technical training [1], [3], [9]. Each latent variable is measured by 4–5 statements on a 5-level Likert scale (1 = strongly disagree; 5 = strongly agree).

3.3.2. Scale appraisal process

The scale is appraised in three steps:

1. **Content appraisal**: 3 experts (1 educational measurement expert, 2 automation lecturers) critique the appropriateness and clarity.
2. **Translation – back-translation**: technical terms (such as OPC UA, virtual commissioning, digital twin) are translated bilingually to ensure international publication.
3. **Pilot test**: conducted with 30 students in addition to the main sample, the results showed that no items needed to be removed; some sentences were shortened to make them easier to understand.

3.4. Data collection process

The research sample included **287 students** (3rd and 4th years) and **22 lecturers** from three campuses: School of Electrical and Electronics, Hanoi University of Science and Technology; School of Electrical and Electronics, Hanoi University of Industry; University of Industry – Thai Nguyen University. All students have studied at least 2 modules using simulations.

The survey is conducted in weeks 8–12 of the term, to ensure learners have had a deep enough experience. Online hybrid deployment (LMS, Google Forms) and paper at the classroom. Invalid surveys (missing >10% data, too fast responses, or unusual patterns) are disqualified before analysis.

For the qualitative part, the research team conducted semi-structured interviews **of 10–12 students** and **6–8 faculty members**, and directly observed several classes. Interview topics focused on: first-time experience with simulation, barriers (installation, license, documentation), effective learning strategies, the role of PBL, comparison between simulation and real labs. These data are encoded using NVivo software for comparison with quantitative results.

3.5. Data Analysis

3.5.1. Reliability and Measurement Value Tests

1. **Cronbach's Alpha**: internal reliability test, with an acceptance threshold ≥ 0.70 [6].
2. **EFA:** confirm the conceptual structure with a KMO ≥ 0.80, Bartlett $p < 0.001$, load factor ≥ 0.50 [9].
3. **CFA: checks** the convergence value and distinguishes it from the following indicators: $\chi^2/df < 3$, CFI/TLI > 0.90, RMSEA < 0.08 [8]. In addition, a CR ≥ 0.70 and an AVE ≥ 0.50 are used to confirm reliability and convergence values.

3.5.2. General method deviation control

To limit Common Method Bias (CMB), the study applied the following measures: mixing the order of the questions, inserting inverted items, neutral instructions, and anonymizing respondents. At the same time, Harman's single-factor testing and the common latent factor model in CFA were implemented for confirmation [7].

3.5.3. Linear Structural Modeling (SEM)

Once the scale is standardized, the SEM is used to test the hypothesis. Indicators reported include: standardized β coefficient, p-value, 95% confidence interval, and R^2. Bootstrap 5,000 samples are applied to ensure stable results even when distributing deviated data [10].

3.5.4. Multigroup analysis and durability testing

Multi-group analysis (MG-SEM) is carried out according to the academic year (year 3 vs year 4) and proficiency level. The process consists of three steps: configuration invariant, load factor invariant, constant invariant. The acceptance criteria are $\Delta CFI \leq 0.01$ and $\Delta RMSEA \leq 0.015$ [8].

The robustness of the model is tested by:

1. Leave-one-out to assess R^2 attenuation.

- Replace the AL intermediate variable with the number of hours/weeks using the simulation to compare the effects.

3.6. Research ethics

The study adheres to the principles of confidentiality, voluntariness, and transparency. Participants are provided with complete information and have the right to withdraw at any time. Data is anonymized at both the individual and institutional levels. Participating universities have approved the implementation of the research. In the case of international publications, the research team is ready to supplement the IRB/IEC dossier as required.

3.7. Research Limitations

The study has three main limitations:

1. **Student self-reported data** can lead to cognitive bias. Although anonymity and reversal measures have been adopted, future research should supplement standardized performance testing (e.g. OSCE engineering).
2. **The facilities are uneven** between schools, so the results reflect efficiency in real-world conditions, not idealization.
3. Quasi-experimental design, the conclusion of causality should be carefully considered and further verified by longitudinal studies.

4. RESEARCH RESULTS

4.1. Sample description and exposure to the simulation

Table 4.1. Demographics and exposure

Character	SV (n=287)	GV (n=22)	Toàn mẫu (n=309)
Training Facilities	ĐHBK HN 38% · ĐH CN HN 37% · TN 25%	ĐHBK HN 41% · ĐH CN HN 36% · TN 23%	–
Gender	Male 72% · Female 28%	Male 77% · Female 23%	Male 72.5% · Female 27.5%
Average age (SD)	21.3 (1.1)	38.7 (6.2)	–

Academic year (SV)	Year 3: 54% · Year 4: 46%	–	–
Teaching Experience (GV)	–	5–10 years: 45% · >10 years: 55%	–
Number of modules with simulation (SV, Self-Report)	2.6 (SD=0.9)	–	–
Simulation hours/week (SV)	3.8 giờ (SD=1.7)	–	–

The near-equilibrium structure of the academic year (54% in year 3; 46% in year 4) allows for the reconciliation of skill accumulation according to "academic maturity" without deviating from the pattern; At the same time, the level of "exposure" to the simulation reaches the useful threshold (an average of 2.6 modules and 3.8 hours/week), so there is a basis for expecting to identify the effects in the SEM model in the following sections. The percentage of lecturers with >10 years of experience reaches 55%, increasing the quality of reference for qualitative interpretation; High male gender deviation is a technical characteristic, but the measurement invariant test presented later showed a stable scale between groups, so the risk of skewed conclusions due to sample structure was low.

4.2. Usage and Experience

4.2.1. Frequency of use by platform

Table 4.2. Frequency (Likert 1–5) & Rate Used

Software/Platform	Average Score	SD	Percentage of students used
Matlab/Simulink	4.2	0.61	93%
Proteus (VSM)	3.8	0.74	74%
Siemens TIA Portal (PLCSIM)	3.5	0.81	61%
Beckhoff TwinCAT 3	2.9	0.95	42%

The model used accurately represents the "skill value chain" of training: Matlab/Simulink leads both the average score and coverage, reflecting the fundamental role in modeling–control; Proteus came in second due to the fast trial-error advantage of the microcontroller module; TIA Portal is good but still depends on infrastructure and lab hours; TwinCAT and Factory I/O are still limited because of startup barriers (licenses, installations, documentation), showing room for improvement if onboarding is increased and associated with the integration project in the final year.

4.2.2. Satisfaction and "quality of experience"

Table 4.3. Satisfied (1–5) with notes

Basis	Average Satisfied	Typical Notes
Matlab/Simulink	4.3	"Standard control lessons, rich documents."
Proteus	4.0	“Fast, intuitive for microcontrollers."
Siemens TIA Portal	3.7	“Industrial proximity; More practice hours needed.”
Beckhoff TwinCAT 3	3.6	“Strong but new; Need methodical guidance.”
Factory I/O	3.7	“3D visualization; Increase excitement when working on projects.”

Satisfaction increases with frequency but is not decisive; in classes with strong PBL/AL, TwinCAT/Factory I/O still achieved high satisfaction even though the usage was not much, confirming the key role of learning design: software is only fully effective when it is accompanied by clear project tasks, timely feedback, and mentors accompanying it.

4.2.3. Duration by school year and proficiency level

Table 4.4. Simulation hours/week

Group	Matlab	Proteus	TIA
3rd year students	3.1h	2.7h	1.9h
4th year students	3.8h	3.1h	2.5h
Students are "highly proficient”*	4.5h	3.6h	3.2h

* *“Highly proficient" = self-rated ≥4/5 on ≥3 platforms.*

The difference of 0.4–0.6 hours/week supports the cumulative hypothesis: the higher the school year, the more practice time, especially evident in TIA and Factory I/O (t-testing shows significant differences). However, the "highly proficient" group had ~1.5–2 times the duration of the regular group, but not all platforms gave direct β proportionally; therefore, "hour" is only a necessary condition, and a sufficient condition is AL/PBL/mentoring to be transformed into a quantifiable skill (see §4.4.2).

4.2.4. Khác biệt mức sử dụng theo cơ sở

Bảng 4.4a. Tần suất TB theo cơ sở

Nền tảng \ Cơ sở	ĐHBK HN	ĐH CN HN	TN	Nhận xét nhanh
Matlab/Simulink	4.3	4.2	4.1	Đồng đều; ĐHBK HN nhỉnh nhẹ
Proteus	3.7	3.9	3.8	ĐH CN HN dùng Proteus mạnh
TIA Portal	3.6	3.5	3.3	ĐHBK HN dẫn nhẹ; TN thấp hơn
TwinCAT	3.0	2.8	2.7	Phụ thuộc onboarding, trợ giảng

Khác biệt giữa các cơ sở là nhỏ (≤0.3 điểm) ngoại trừ nhóm gần công nghiệp (TIA, TwinCAT, Factory I/O) vốn nhạy với hạ tầng, license và trợ giảng; điều này báo trước kết quả đa nhóm: nơi nào tổ chức được onboarding và capstone tốt thì hệ số đường dẫn ở các nền tảng tích hợp sẽ cao hơn.

4.2.4. Differences in usage by basis

Table 4.4a. TB frequency by basis

Platform \ Base	Hanoi University of Science and Technology	Hanoi University of Technology	TN	Quick Comments
Matlab/Simulink	4.3	4.2	4.1	Uniformity; Hanoi University of Science and Technology is slightly slight
Proteus	3.7	3.9	3.8	Hanoi University of Technology uses powerful Proteus
TIA Portal	3.6	3.5	3.3	Hanoi University of Science and Technology leads slightly; Lower TN
TwinCAT	3.0	2.8	2.7	Dependent onboarding, teaching assistant

The difference between the facilities was small (≤0.3 points) except for the near-industrial group (TIA, TwinCAT, Factory I/O) which is sensitive to infrastructure, licensing and teaching assistants; This foreshadows multi-team results: where onboarding and capstone are well organized, the path coefficient in integrated platforms will be higher.

4.3. Reliability and Scale Value

4.3.1. Internal Trust

Bảng 4.5. Cronbach's Alpha

Skill groups (latent variables)	Item Number	Alpha
Modeling (Matlab/Simulink)	5	0.89
Embedded Design (Proteus)	5	0.87
PLC Programming (TIA Portal)	5	0.85
Distributed Control (TwinCAT)	5	0.83
System Integration (Factory I/O, SCADA mini)	5	0.81
Digital Industrial Interaction (OPC UA/SCADA/Digital Twin)	5	0.88

An Alpha from 0.81 to 0.89 indicates a good consistency scale, not falling into repetition (too high) or noisy (too low). Notably, the two newer scales for students (TwinCAT, Integrated) still reach a good threshold, confirming that learners have grasped the right focus of the concept even though the duration of the experience is not much.

4.3.2. Structure and convergence–differentiation

Table 4.6. EFA (KMO, Bartlett, extraction variance, load)

Index	Value	Explain
KMO	0.91	Very good (high shrinkability)
Bartlett (Sig.)	<0.001	The correlation is strong enough to extract factors
Số nhân tố trích	6	Matching the 6-skill model
Phương sai trích	68.4%	Strong (≥60% is usually good)
Tải nhân tố (min–max)	0.61–0.84	No ominous cross-loading

EFA confirms that the six-factor structure is exactly as designed, without significant cross-loading, setting the stage for the CFA to operate smoothly without "manual adjustment"; this increases the conceptual credibility before entering SEM.

Table 4.7. CFA Suitability

CFA Index	Value	Threshold	Assess
χ^2/df	2.15	<3	Tốt
CFI	0.94	>0.90	Tốt
TLI	0.92	>0.90	Tốt
RMSEA	0.048	<0.08	Tốt
SRMR	0.051	<0.08	Tốt

Table 4.8. Load, CR & AVE

Latent variables	λ (min–max)	CR	AVE	Conclude
Modeling (Matlab)	0.68–0.84	0.89	0.61	Good convergence
Nhúng (Proteus)	0.66–0.82	0.88	0.59	Stable
PLC (TIA)	0.63–0.79	0.86	0.55	Satisfactory
Disperse (TwinCAT)	0.62–0.78	0.85	0.53	Satisfactory
Integrated (Factory I/O)	0.61–0.77	0.84	0.52	Satisfactory
Digital Branch (OPC UA/SCADA/DT)	0.67–0.83	0.88	0.60	Good convergence

Suitable set of indicators (high CFI/TLI; low RMSEA/SRMR) with CR ≥0.84, AVE ≥0.52 proving that the measurement quality meets international standards; The Fornell–Larcker value test shows that the concepts are sufficiently "far apart", ensuring that when SEM estimates, the effects are not interfered with by conceptual overlap.

4.4. Structural Modeling (SEM)

4.4.1. Direct Impact

Table 4.9. Direct path (β, standardized)

Relationship (hypothetical)	β	SE	CR/t	p	Conclusion
Matlab → Modeling Skills	0.42	0.06	7.05	<0.001	Accept
Proteus → Embedded Design Skills	0.37	0.07	5.44	<0.001	Accept
TIA Portal → PLC Programming Skills	0.34	0.07	4.92	<0.001	Accept
TwinCAT → Distributed Control Skills	0.28	0.09	3.10	0.002	Accept
Factory I/O → System Integration Skills	0.26	0.08	3.25	0.001	Accept

β order is true to each platform's "strengths": Matlab serves as an "anchor" for modeling (strong β 0.42), Proteus and TIA are "manipulative levers" for embeddings and PLCs (quite β 0.37–0.34), while TwinCAT and Factory I/O create an integrated gateway (medium β 0.28–0.26) but have strategic implications at the capstone stage; In other words, each platform closes a clear link in the skill formation roadmap from the → deployment → integration model.

4.4.2. Indirect impact through AL – Interaction – PBL

Table 4.10. Intermediate (Bootstrap 5,000)

Indirect Lines	β_indirect	95% CI	p	Conclude

Simulation → Interaction → Skills	0.12	[0.07; 0.18]	<0.001	Intermediate section
Simulation → Active Learning → Skills	0.14	[0.09; 0.20]	<0.001	Intermediate section
PBL → Simulation → Skills	0.10	[0.05; 0.17]	0.002	Intermediate section

The three intermediate channels are all significant, with AL being the strongest bridge; Summarizing shows, about 26–28% of the impact of simulation does not go directly to skills but "flows" through the way learning is organized—especially with near-industrial platforms such as TwinCAT/Factory I/O, where the level of initiative, team interaction, and project product determines the speed at which the learning curve is broken.

4.4.3. Explanatory power of the model

Table 4.11. R^2 by skill group

Dependent variable (skill)	R^2	Explain
Modeling	0.47	Highest; "anchored" by Matlab
Embedded design	0.39	Fairly; Proteus Leverage
PLC Programming	0.36	Fairly; Increase with increased hours TIA/mentoring
Distributed Control	0.31	Average; sensitive to mentoring/onboarding
System Integration	0.29	Average; need PBL to "pull”
Digital Industrial Interaction	0.41	Cao; nhờ OPC UA/SCADA/Digital Twin

The model explains 29–47% variance, i.e., simulation is an important lever but not enough to replace the real lab experience, Math-Physics platform, and internships; a viable strategy to raise R^2 is to increase AL/PBL/mentoring (as it has been proven to be an effective indirect channel) and integrate performance evaluation (technical OSCE) to align simulation with execution capacity.

4.4.4. Group differences (school year, campus) and durability testing

Table 4.12. Multi-group & durability summary

Compare	Key results	Operational implications
Year 3 vs Year 4	ΔCFI=0.004; β(TIA)+0,08; β(Factory)+0,07	Increase hours/week in the final year + built-in capstone
Three campuses	Invariance for the most part; slight difference TIA/TwinCAT	Investment in onboarding, licensing, teaching assistantship
Leave-one-out	Matlab is "anchor"; TIA is "leverage”	Holding the Matlab–TIA axis in the program
AL vs Hours/Week	Stronger than hour/week AL (indirect)	Focus on learning design rather than just increasing hours

Measurement invariant testing (very small ΔCFI/ΔRMSEA) ensures a valid comparison; The path factor in year 4 is significantly higher with TIA→PLC and Factory I/O→ Integration is in line with the reality of increased lab hours and capstone modules. According to the establishment, the differences are mainly concentrated in the group near industry, reflecting infrastructure conditions and pedagogical support; durability analysis confirms that Matlab is the "anchor" variable (excluded from the model that makes the R^2 of the model fall sharply) and that the quality of learning (AL) is more important than the total hours/week when considering the indirect effect.

4.5. Learning Process Indicator

Table 4.13. Correlation (SV, n=287)

Get lost	1	2	3	4
1. TB Frequency	–	0.43	0.47	0.41
2. Satisfied TB		–	0.45	0.38
3. Active Learning			–	0.52
4. PBL Level				–

(All $p<0.01$)

The AL–PBL pair had the strongest correlation (0.52), indicating that when involved in the real project, students were forced to be more proactive; frequency and satisfaction increased accordingly, but only played a supporting role, not replacing the regulatory role of AL/PBL, which had been affirmed by meaningful indirect lines in SEM.

4.6. Qualitative results: the "why" mechanism

Table 4.14. Shortened Themes & Illustrations

Subject	Core Content
Intuitive & safe	Try risky/costly scenarios on simulations; Learning through mistakes
Industrial Proximity	TIA / OPC UA is the same as the company's environment; Reduce surprises when practicing
Boot Barrier	Installation, licensing, lack of Vietnamese documents; especially in TwinCAT/TIA
PBL & Team Roles	Split shoulders – peer review – demo; Increased accountability and speed of completion
Mentoring & Practical Hours	2-3 tutoring sessions close to the beginning of the term decided to overcome the "breaking point" of the learning curve

Qualitative topics act as a "bridge" to the mechanism seen in SEM: when onboarding, PBL and mentoring are well organized, the level of initiative and interaction increases markedly, thereby improving the effectiveness of high-barrier platforms (TwinCAT/Factory I/O); Conversely, if there is an installation or licensing problem, the frequency and satisfaction decline, leading to a weakening of the impact coefficient.

In summary, the table series 4.1–4.14 sums up a consistent and easy-to-understand picture: (i) the survey sample has a sufficiently large exposure to the simulation, the measures have been validated (Alpha/EFA/CFA), so the SEM results are reliable; (ii) the direct impact of each software matches its pedagogical function—MATLAB/Simulink enhances modeling-control skills, Proteus promotes embedded design, TIA Portal reinforces PLC programming-operation, and TwinCAT and Factory I/O extends to distributed control and system integration; (iii) about a quarter to nearly one-third of the effects do not go directly from software to skills, but go through the "bridge" of active learning, interactive learning, and project-based teaching—that is, it is not enough to increase the number of hours of software use, there must be a design of learning activities that forces learners to try and wrong, exchange and make products; (iv) the gap between the school year/campus is mainly due to lab hours, infrastructure and teaching assistants, so it can be improved by specific interventions such as onboarding the first 3 sessions (installation–mini-shift running–error injection/diagnostics), integrated capstone linking to industrial scenarios and OSCE-style competency assessments. In short: simulation is leverage, but it is design learning that turns that leverage into measurable practical skills.

5. CONCLUSION

This study confirms that **simulation software** is an important tool to help improve practical skills for students in Electrical – Automation. On the basis of data from 309 participants, the quantitative and qualitative results show that the simulation is not only illustrative, but also serves as a **substantive** training lever.

Firstly, simulation platforms demonstrate a clear and true impact on pedagogical functions: MATLAB/Simulink supports modeling skills; Proteus develops embedding skills; Siemens TIA Portal consolidates PLC programming; TwinCAT enhances distributed control; Factory I/O promotes system integration skills. The order of impact coefficients reflects a **reasonable capacity pathway** from academic to industrial application.

Second, the effectiveness of simulation is highly dependent on **learning design**. Intermediate channels – active learning, interactive learning, and PBL – account for about 1/4 to 1/3 of the overall impact. In particular, active learning plays the most important role, suggesting that simply increasing the number of simulation hours is not enough without an environment that encourages experimentation and reflection.

Third, the difference between the academic year and the training institution proves that in addition to tools, infrastructure, onboarding and capstone play a decisive role. Final year students have a more pronounced level of progress, reflecting the process of accumulation and engagement with the actual project.

In short, numerical simulation is **an essential tool but does not automatically create skills**; it only maximizes when associated with the right pedagogical strategy. Therefore, training institutions need to combine simulation with PBL, mentoring and standardized assessment to turn virtual experiences into **sustainable professional competencies** for students.

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