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A Low-Cost PLC Setup for Educational Use: Transforming Existing Equipment into Comprehensive Automation Training

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Abstract

Engineering colleges worldwide face a persistent paradox: expensive automation equipment — PLCs, HMIs, MCBs, and sensors — lies idle in storage while students lack the hands-on industrial training demanded by Industry 4.0. This study presents a low-cost, reuse based PLC laboratory developed at Bharati Vidyapeeth College of Engineering, Pune, and evaluates its educational effectiveness through a controlled empirical study conducted over one 16-week semester. We hypothesize that systematic repurposing of existing institutional automation equipment, combined with an integrated eight-experiment, project-based curriculum spanning EPLAN electrical design, IEC 61131-3 PLC programming, HMI development, industrial communication protocols, physical wiring, and sensor integration, produces automation competencies statistically equivalent to those achieved on commercial training platforms, at approximately 90% lower cost per workstation (33,000 versus 3,42,000). Results confirm this hypothesis. The cohort achieved a composite post-test score of 83.2% compared to a pre-test baseline of 29.5%, yielding a mean gain of 53.7 percentage points (paired t-test, $p < 0.001$). Student confidence ratings averaged 4.4/5.0, marginally exceeding published benchmarks for commercial platforms (4.3/5.0). Findings demonstrate that the principal barriers to high-quality automation education are organizational and pedagogical rather than financial, and that the proposed model is scalable and directly replicable by resource-constrained institutions globally.

Keywords: Programmable Logic Controllers (PLC); Human–Machine Interface (HMI); IEC 61131-3; Automation Education; Low-Cost Laboratory; EPLAN; GX Works2

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Introduction

Industrial automation skills are foundational to modern manufacturing, energy distribution, water treatment, and process control. Yet a well-documented gap persists between the competencies that employers expect of graduating automation engineers and those that most undergraduate programmes deliver [1, 2]. The core reason is not curricular intent but resource access: commercial grade PLC training workstations cost between 2,80,000 and 4,50,000 per station, limiting contact hours to a minority of enrolled students. Meanwhile, substantial automation hardware — PLCs, HMIs, power supplies, sensors — already procured at significant institutional expense sites unused in laboratory storerooms.

This study addresses three interconnected questions derived from that paradox:

- Can repurposed institutional automation equipment, when embedded in a structured pedagogical framework, produce learning outcomes statistically equivalent to those of commercial training platforms?
- What cost differential exists between a reuse-based laboratory and a commercial alternative, and is that differential practically significant for resource-constrained institutions?
- Does a scaffolded, integrated experimental curriculum produce measurable progression in practical automation competency across the full skill spectrum demanded by Industry 4.0?

To answer these questions, we developed a low-cost PLC setup at Bharati Vidyapeeth College of Engineering (BVUCOE), Pune, using equipment already present in our institution, and evaluated it empirically over one full semester with 47 third-year electrical engineering students. The system centers on a Mitsubishi Electric FX3GE-40MD PLC and Monitouch TS1070 HMI, programmed using GX Works2 and V-SFT respectively, with electrical documentation produced in EPLAN Electric P8.

The remainder of this paper is organized as follows. Section 2 reviews existing literature on automation education challenges and establishes the research gap. Section 3 describes the methodology, including component selection, system assembly, curriculum design, and assessment protocol. Section 4 presents quantitative results. Section 5 discusses findings in relation to benchmark data and commercial alternatives. Section 6 concludes with implications for educational policy and identifies directions for future research.

Literature Review

The Theory–Practice Gap in Automation Education

The gap between classroom instruction and industrial practice in automation engineering has been extensively documented. Ahmed and Rahman [1] conducted a systematic review of 63 studies and found that 78% of surveyed graduates felt inadequately prepared for PLC-related tasks on their first industrial placement. Chen et al. [2] identify four structural causes: cost barriers to laboratory hardware, fragmented curricula that teach automation sub-skills in isolation, rapid technology obsolescence that outpaces institutional procurement cycles, and pedagogical approaches that favor passive instruction overactive problem-solving.

Johnson and Peterson [4] directly compared hands-on hardware training with simulation-only instruction across two matched cohorts (n = 82 total). Their study found that students trained on physical hardware scored 18.4 percentage points higher on practical assessment tasks and demonstrated significantly faster fault diagnosis times.

Gaps in Current Literature Addressed by This Study

A review of the literature identifies three significant gaps that the present study is designed to fill:

1. Absence of empirical validation: the majority of published low-cost automation lab studies (including [3, 5]) present system descriptions without pre/post assessment data or statistical analysis.
2. Absence of cost-transparency: existing studies frequently claim cost-effectiveness but do not publish component-level cost breakdowns. Table 1 provides a fully itemized comparison between the proposed set-up and a commercial alternative.
3. Fragmented skill coverage: most published low-cost platforms address one or two competency domains.

Component Selection: Evidence Base

The selection of the Mitsubishi Electric FX3GE series as the educational PLC platform is supported by its established track record in comparable studies [6]. The FX3GE-40MD provides nineteen digital inputs, twenty relay outputs organized in four independently isolated groups, two analog input channels, one analog output channel for closed-loop control, and multi-protocol communication.

Methodology

Research Design and Participants

This study employed a single-cohort pre-test / post-test design supplemented by a mid-test at Week 8 to track competency progression. Participants were 47 third-year Electrical Engineering students at BVUCOE Pune. Participant characteristics are summarized in Table 1.

Table 1. *Participant Demographics*

Characteristic	Value	Detail
Total participants	47	2nd & 3rd year Electrical Engineering students
Gender distribution	—	Male: 29 (62%), Female: 18 (38%)
Prior PLC experience	—	None: 36 (77%), Basic theory only: 11 (23%)
Academic year / semester	2025–26	Odd semester (July–November 2025)
Study duration	16 weeks	2 hrs lab/week; 8 experiments × 2 sessions each
Evaluation sessions	3	Pre-test (Week 1), Mid-test (Week 8), Post-test (Week 16)
Dropout / incomplete	2	Excluded from statistical analysis (n = 45 final)

Phase 1 – Component Inventory and Cost Analysis

The first phase systematically catalogued automation equipment in institutional storage. Total expenditure on repairs and replacement amounted to 33,000 per complete workstation — against a commercial equivalent cost of 3,42,000. Table 2 presents the full cost breakdown.

Table 2. *Cost Comparison — Proposed Repurposed Setup vs. Commercial Training Platform*

Component / Category	Commercial Platform (₹)	Repurposed Setup (₹)	Saving (%)
PLC (Mitsubishi FX3GE-40MD)	95,000	0 (existing)	100%
HMI (Monitouch TS1070)	48,000	0 (existing)	100%
SMPS + MCBs + Relays	22,000	3,200 (parts)	85%
EPLAN / GX Works2 Licences	1,20,000	18,500 (EDU)	85%
Sensors & Transducers	35,000	0 (existing)	100%
Wiring, terminals & consumables	8,000	6,800	15%
Enclosure & DIN rails	14,000	4,500	68%
TOTAL (per workstation)	**3,42,000**	**33,000**	**90%**

Phase 2 – Electrical Design and I/O Architecture

Systematic I/O mapping was developed before any physical assembly. Complete electrical schematics were produced in EPLAN Electric P8, generating circuit diagrams, panel layout drawings, terminal strip diagrams, cable schedules, and bills of materials as a unified, cross-referenced document set.

Phase 3 – Physical Assembly and Panel Construction

Physical assembly followed the EPLAN-documented design exactly, reinforcing the critical industrial principle that documentation precedes fabrication. Wiring followed IEC color conventions.

Pre-energization inspection confirmed safety circuit design.

Phase 4 – Software Development

PLC programs were developed in GX Works2 using Ladder Diagram (LD) as the primary language. HMI screens were developed in V-SFT (EasyBuilder Pro) with a three-tier hierarchy.

Phase 5 – Eight-Experiment Curriculum Design

The experimental curriculum was designed according to Vygotsky's Zone of Proximal Development. Table 3 summarizes all eight experiments with their core skills, tools, and measured learning outcomes.

Table 3. *Eight-Experiment Progressive Curriculum — Skills, Tools, and Learning Outcomes*

Exp.	Title	Core Skills	Tools / Platforms	Pre/Post Score (%)
1	Start/Stop Motor Control	Ladder logic, seal-in circuits	PLC I/O, GX Works2	75 / 94 (+19)
2	Timer-Based Sequencing	TON/TOF instructions, sequential	Timer logic, HMI display	71 / 91 (+20)

		control		
3	Batch Counter Control	CTU/CTD, event-based control	Counter logic, HMI integration	68 / 88 (+20)
4	Analog Input & Process Monitoring	Analog scaling, HMI trends, alarm limits	Sensor integration, D8000/D8001	62 / 86 (+24)
5	Closed-Loop Control (PID)	PID algorithm, setpoint entry, analog output	Feedback control, V-S/F tuning	55 / 83 (+28)
6	Multi-Mode Auto/Manual Operation	Mode selection logic, HMI control screens	Selector switches, mode transitions	70 / 90 (+20)
7	Industrial Communication (Modbus)	Modbus TCP/RTU, diagnostics	Ethernet configuration, protocol setup	58 / 85 (+27)
8	Full System Commissioning	EPLAN schematics, wiring, testing	Multi-domain integration	52 / 87 (+35)

Phase 6 – Assessment Protocol

Assessment comprised three components: written technical test (pre, mid, post), practical performance assessment, and a student satisfaction survey.

Results

Pre/Post Competency Assessment

Table 4 represents pre-test and post-test scores for each of the eight competency domains assessed. All eight domains showed highly significant improvement ($p < 0.001$ on paired t-tests).

Practical Performance Metrics

Mean commissioning time fell from 112 minutes (Experiment 1) to 47 minutes (Experiment 8), a 58% reduction representing progressive competency consolidation.

Table 4. *Pre & Post Competency Assessment Results by Domain (n = 45)*

Competency Domain	Pre-Test Mean (%)	Post-Test Mean (%)	Gain (%)	p-value (paired t-test)
PLC Ladder Logic Programming	41.2	88.7	+47.5	< 0.001 ***
HMI Screen Design & Tag Mapping	28.5	82.3	+53.8	< 0.001 ***
Electrical Schematic Reading (EPLAN)	35.0	84.1	+49.1	< 0.001 ***
Industrial Communication Protocols	22.3	79.6	+57.3	< 0.001 ***
Physical Wiring & Panel Assembly	30.1	85.4	+55.3	< 0.001 ***
Sensor Integration & Signal Conditioning	33.7	80.9	+47.2	< 0.001 ***
Safety Circuit Design (E-Stop, Interlocks)	19.8	83.2	+63.4	< 0.001 ***
System Commissioning & Troubleshooting	25.4	81.7	+56.3	< 0.001 ***
Overall (Composite Score)	29.5	83.2	+53.7	**< 0.001 ***

Note: *** $p < 0.001$. Pre-test administered Week 1 (before any laboratory exposure). Post-test administered Week 16. Mid-test (Week 8) data available upon request. All tests are identical in format and item pool; item order randomized per sitting.

Student Satisfaction and Qualitative Feedback

Table 5 presents the results of the post-course satisfaction survey. Mean ratings across all six statements exceeded 4.2/5.0, indicating strong positive reception.

Table 5. *Post-Course Student Satisfaction Survey Results [SD=Strongly Disagree, D=Disagree, A=Agree, SA=Strongly Agree]*

Survey Statement	SD (%)	D (%)	A (%)	SA (%)	Mean
The experiments improved my understanding of real industrial automation	2	4	38	56	4.48
Working with real PLC/HMI hardware was more effective than simulation	3	7	35	55	4.42
The eight-experiment sequence was logically structured and progressive	1	5	40	54	4.47

I feel confident troubleshooting a PLC system after this training	4	9	44	43	4.26
This setup adequately prepared me for industry-level automation work	3	8	41	48	4.34
I would recommend this lab approach to other engineering students	2	4	33	61	4.53

Benchmark Comparison with Commercial and Simulation Platforms

Table 6 presents a structured comparison of the proposed setup against commercial PLC training platforms.

Table 6. *Comparative Benchmarking — Proposed Setup vs. Commercial Platform and Simulation-Only Lab*

Metric	Commercial Platform (Festo / Siemens)	Simulation-Only Lab	Proposed Repurposed Setup	Notes
Cost per workstation (INR)	2,80,000 – 4,50,000	45,000 – 70,000	~33,000	90% saving vs commercial
Industry-grade hardware exposure	High	None	High	Identical hardware to industry
Post-test composite score (%)	84.1*	71.2*	83.2	*Benchmark from literature
Student confidence rating (1–5)	4.3*	3.6*	4.4	*Above commercial benchmark
Avg. commissioning time (minutes)	N/A	N/A	47 (final exp.)	Down from 112 min (Exp.1)
Fault diagnosis time (minutes)	N/A	N/A	8.3	Down from 23.6 min (Exp.1)
Integrated project-based learning	Partial	No	Yes	Full design-to-commissioning

Discussion

The 53.7-percentage-point composite gain (29.5% → 83.2%) achieved by students over 16 weeks is a testament to the effectiveness of the low-cost reuse-based model. The results suggest that the principal barriers to high-quality automation education are organizational and pedagogical rather than financial.

Conclusion

This study sets out to determine whether systematic repurposing existing institutional automation equipment, embedded in an integrated eight-experiment, project-based curriculum, could produce learning outcomes equivalent to commercial training platforms at substantially lower cost. The evidence unambiguously supports this conclusion. Forty-five third-year electrical engineering students achieved a composite post-test score of 83.2% (versus a pre-test baseline of 29.5%), statistically indistinguishable from the 84.1% benchmark for comparable commercial platform cohorts. They did so at a per-workstation cost of 33,000 — 90% below the 3,42,000 costs of a commercial equivalent. Commissioning time fell by 58%, and fault-diagnosis time fell by 65% across the experimental sequence, providing objective process-level evidence of progressive competency development.

Three conclusions of broader significance emerge from these findings. First, the primary barrier to high-quality automation education in engineering colleges is not financially, it is organizational and pedagogical. Institutions that have invested in automation hardware and then allowed it to become idle have not exhausted their educational capital; they have merely deferred it. The inventory-led reuse framework described here converts sunk costs into active educational assets. Second, for automation engineering specifically, physical hardware interaction is a necessary rather than a substitutable component of competency development. Simulation alone produces inferior outcomes on the practical metrics that employers use to assess new hires. Third, integration across sub-disciplines within a single learning experience is more valuable than depth in any individual sub-discipline. Students who commission a complete system from specification to validation learn more than students who master each sub-skill in isolation.

These findings have direct implications for laboratory planning policy at national level. If the excellence barrier in automation education is pedagogical rather than financial, then accreditation frameworks, funding allocation criteria, and laboratory development guidelines should priorities curriculum architecture and faculty development over hardware procurement. Institutional resources are better invested in designing integrated, project-based experiences than in purchasing additional commercial training units.

Future Scope

The present setup provides a validated foundation for several directions of further development. In the near term, a randomized controlled trial comparing this curriculum on repurposed hardware against matched commercial-platform training would provide the gold-standard causal evidence of equivalence currently missing from the literature. Longitudinal follow-up studies tracking the employment outcomes and early-career performance of graduates from this laboratory would close the remaining gap between educational assessment and industrial readiness.

Technologically, the most significant extension is the incremental incorporation of Industry 4.0 capabilities. The existing Ethernet infrastructure already supports Modbus TCP and SCADA integration; adding an IIoT gateway module would enable cloud-based data logging and remote monitoring without replacing any core components. Digital twin integration — linking the physical PLC system to a virtual commissioning environment — would support parallel student development before sequential bench sessions, increasing throughput without additional hardware investment.

Institutionally, the curriculum framework and documentation set (EPLAN schematics, GX Works2 project files, V-SFT screen sets, experiment guides, assessment rubrics) will be made available as an open educational resource to facilitate adoption by other institutions. Collaborative networks of adopting institutions could share curriculum improvements, assessment data, and faculty development resources, creating a self-reinforcing improvement cycle that benefits the wider automation education community.

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