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The changing face of engineering laboratories for outcome-based education (OBE): A case study of a learning experience in PLCs and automation laboratories

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***Abstract*—Today, the urge for outcome-based education (OBE) is the watchword in the education field, and so is its need! Although theoretical information is always necessary, laboratories are at the top of the hierarchy for imparting technical competencies to engineering graduates. The current state of modernization makes it harder to provide a high-quality laboratory experience due to rising complexity and, consequently, higher setup costs. A survey of traditional laboratories across engineering colleges suggests that available experimental setups are primarily objective-driven, with limited scope for creativity. A well-planned laboratory setup enhances the effectiveness of teaching the multiple facets of an experimental topic. This perspective is examined through a case study of the PLCs and Automation (PLCA) laboratory at Department of Electronics and Telecommunication, Jayawantrao Sawant College of Engineering, Pune, India. In contrast to fixed, tightly bound designs, the proposed laboratory setup provides the flexibility to develop a wide range of real-time applications. Such a setup can be developed at minimal cost by giving careful consideration to the provisions required to support all possible investigations related to the experimental topic. The level of creativity fostered and the ability to address open-ended problem statements in the laboratory align with engineering accreditation standards. These criteria emphasize students' capabilities to design and conduct experiments, analyze and interpret results, and work effectively in teams. To further enhance the learning experience, this article also proposes various instructional approaches implemented in the laboratory using digital tools and techniques.**

***Keywords*—Laboratory, Outcome-Based Education (OBE); Experiment Learning Outcome (ELO); Programmable Logic Controller (PLC); HMI; SCADA.**

***JEET Category*—Research**

I. INTRODUCTION

ENGINEERING education is more about learning through experience and practice. Thus, from the most primitive days of the engineering program, instructional laboratories have been a vital part of engineering graduation, as stated by Feisel et.al. (2005). The emphasis on laboratories has varied over the years. Despite the abundance of research articles on curriculum and teaching methodologies, the field of laboratory instruction has received relatively less attention. It was reported in Wankat (2004) that only 6.5 percent of the papers used "laboratory" as a keyword in the articles published in the *Journal of Engineering Education* from 1993 to 1997. From 1998 to 2002, the inclusion rate for laboratory practices was 5.2%. Effective learning in the engineering laboratory becomes difficult due to several subsequent reasons. Changes in the curriculum or the list of experiments necessitate ongoing investment, but funds are insufficient. Frequent staff career migration and availability of qualified staff are dwindling as many engineering teachers found themselves shifting to industry after COVID-19. The laboratory infrastructures with fixed and specific scopes are purchased and cannot be upgraded. The proposed resources created in the laboratory demands minimum upgrading as the setup is flexible. There is a minimum dependency on the instructors due to the learning material, such as experiment videos on QR codes, the PPT and quizzes to test self-understanding, virtual labs and, simulators to practice at home other than lab hours. National Board of Accreditation (NBA) has released some POs i.e., statements on the knowledge, skills, and attributes an engineering graduate should inculcate after completing the program, referred from websource:nbaind.org (2016). It is much more likely to specify experiment learning objectives

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(ELO) for laboratory work. A general goal is to correlate conceptual phenomena with practice or realize them through theoretical learning, as by Bisantz et.al. (2002).The ABET Engineering Criteria 2000 has resulted in increased attention to objectives, including some associated with the laboratory. The psychomotor objective is suggested in Dominik et.al. (2023) for the laboratory, as students should be able to demonstrate competence in the selection, modification, and operation of appropriate engineering tools and resources.

This requires the flexibility in the laboratory setting for modifying the viewpoint of learning. Andersson (2020) explains, "Experimenters do not settle with collecting numbers. They create unique conditions to explore the world around them. At the end of the day, experimenters see the world more through an artist's eye than through the eye of an accountant.

II. Instructional Laboratories as the Heart of Engineering Education

In the early decades, engineers were trained by the British apprenticeship system taught in an apprenticeship program, which was also learning by doing. Even today, lab learning still accounts for a larger portion of engineering education, as found from websource:abet.org (2019). Many engineering programs started in the mid-19th century at Cornell (1830), followed by major schools such as Union College, Yale, and MIT. As influenced by the Industrial Revolution and the Morrill Land Grant Act of 1862, these schools developed curricula highly emphasizing laboratory instruction ranging from electrical, telecommunication, mechanical, civil, and chemical engineering. Further, as stated by Grayson (1993), the need to guarantee the caliber of engineering programs evolved and resulted in the formation of accreditation bodies, and the American Institute of Chemical Engineers (AIChE) in the United States was accredited.

The quality grading process (accreditation), however indirect, had certainly enforced the transformation in the nature of engineering laboratories. Continuing the efforts of quality engineering education globally, the Engineers' Council for Professional Development (ECPD), the Accreditation Board for Engineering and Technology, and the National Board of Accreditation came into the picture as referred from Reynolds (1983).

In 1993, nine standards were published according to the original ECPD accreditation criteria, which meant accreditation to engineering disciplines namely, mechanical, electrical, chemical, civil, metallurgical, and mining engineering. Nowadays, guidelines are framed for the applied programs of engineering, like information technology, electronics and telecommunications, instrumentation, and so on. To sum up the guidelines of all accreditation bodies, each program is evaluated qualitatively as well as quantitatively. The evaluation is based on the development of students, the availability of well-qualified and expert teaching staff and supporting staff, and institutional policy to cope with the needs of industry and society. The metrics to justify are the physical facilities and the curricula designed by independent colleges or universities. Although the phrase "laboratories" peculiarly did not emphasize it, it is implicitly included in physical facilities. No engineering college can be imagined without good laboratories as reported from web source: cems.umn.edu (1888).

An Engineering Foundation Conference held in 1983 attested to the importance of laboratories in engineering education and made recommendations that they be strengthened, as described by Stephan (2002). Further, the reduced cost of the personal computer and its incorporation into the laboratory have helped to reduce the need for expensive equipment and also enhanced the learning experience in the laboratory through assistance in design and simulations.

III. Different Digital Approaches for Improving Quality of Laboratory

Some innovative teaching methods in automation and control laboratory are described in Bewoor, et.al. (2022). Following section described the advent of various digital approaches deployed in the lab for training the students. It helped them to create interest and seek the challenging course like PLC & Automation through engaging by modular activities. The activities include (i) Accessing study material and video on QR code (ii) Computer Simulation and animated program editor (iii) Power point presentation with interactive MCQs and last but very effective is (iv) To use a flexible setup to build the open-ended problem statements.

A. Study Material on a QR Scan along with demonstration videos:

The new generation's interest in using mobile devices for learning has grown significantly. For them, mobile learning is an appealing alternative because of its accessibility, convenience, and integration with daily life. For the study material, QR codes are adhered to the setup in this lab. Students need to simply scan the QR code without any other resources. they will be directed to the content management tool like Drop-box. Now they can choose any content of their interest. e.g. conduction video, a hardware interface datasheet, software instructional manual, etc.

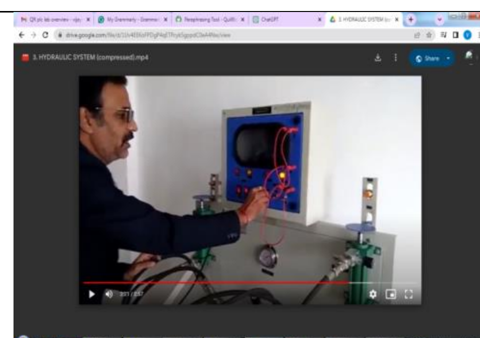

Fig. 1(a) QR code for Dropbox study material

Fig. 1(b) Recorded video on particular topic in the relevant section of Dropbox material

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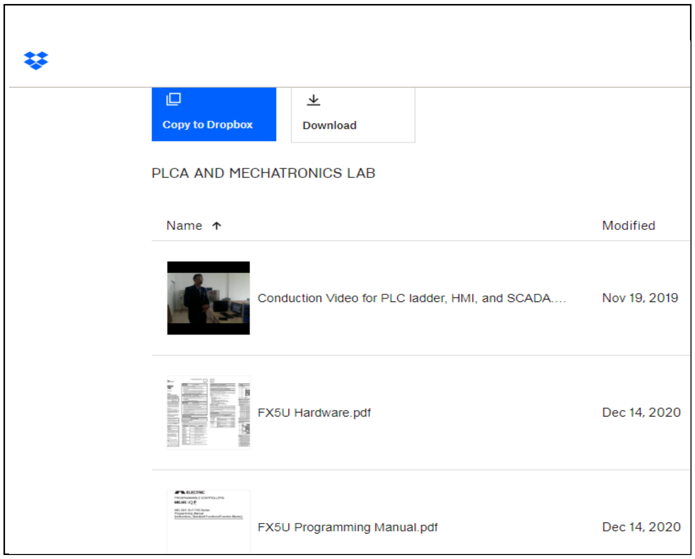


Fig. 1(c) Screenshot of Example content in the Dropbox

B. Hands-on conduction of the laboratory practice / computer simulation/ Virtual labs:

PLC lab needs various resources as described below:

- The Ladder Programming (GXWorks) is an efficient representation for discreet logic that offers advantages like Intuitive and self-documenting, an excellent pictorial representation based on well-understood circuit design concepts and excellent debugging tools as illustrated by Harpreet Bedi et.al. (2023)
- HMI (GTDesigner3) includes general functionality such as alarming, trending, reporting and remote maintenance which is described by Erwin et.al. (2014).
- SCADA (GraphWorkX32 is a central control system that consists of controllers network interfaces, input/output, communication equipment and software. SCADA systems are used to monitor and control the types of equipment in the industrial process which include manufacturing, production, development and fabrication demonstrated by Khairy et.al. (2016).
- The laboratory uses the MITSUBISHI-make FX5U Programmable Logic Controller (PLC) with detailing in Users' manual: MELSECiQ-F FX5U (2021).

The aforementioned software is bulky and also requires a license. As a result, the open-source Pico-soft/Ladder-Sim application was provided to the students, enabling them to simulate PLC programs even at home. While not utilized in the suggested lab, alternatives for hardware realization can be achieved with VR assistance. The 3D models of PLCnext learning kit is available using Blender and for interaction purpose, the Unity engine is taken into account as per the clue given in Vaananen et.al. (2010). Considering high cost of AR/VR setups, the alternative of animated system for car parking is exercised by the students.

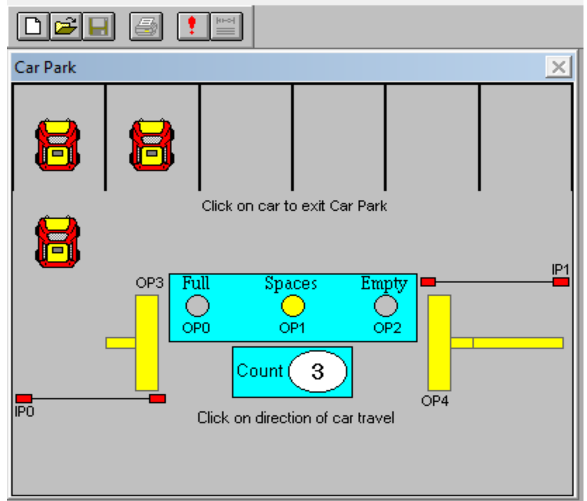
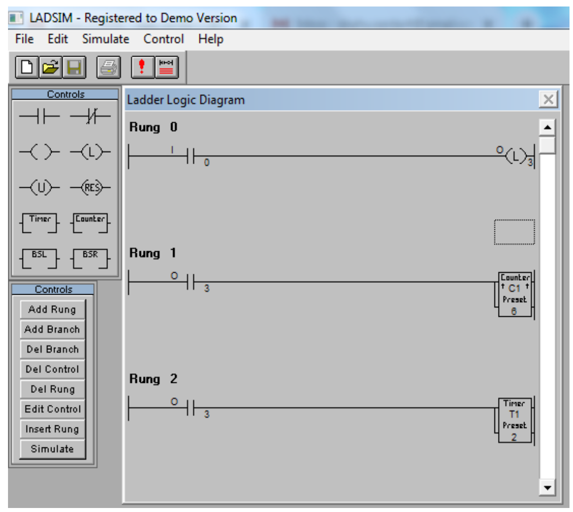


Fig. 2(a) The Animated Car Parking system



(b). The library of required components and editable ladder program

It is one of the systems available in Ladder-Sim where animated the car parking system will work according to the ladder program. Any live changes in the program will reflect the effect in the animated system components.

The virtual labs in various disciplines of Science and Engineering are initiated by the Ministry of Human Resource Development collaborating with different IITs and other institutes of repute, as described by Elmoazen et.al. (2023)

.Some student group has taken advantage of a virtual lab for PLC developed by COEP, Pune.

However, as discussed in Section VI, the virtual laboratories received poor feedback, and the possible reasons were subsequently discussed with the students.

C. Use of interactive presentations with the quizzes for creating interest and self assesment

The study strongly recommends PowerPoint narrations with embedded quizzes, which reported an overwhelming response from the students. The PPTs were made engaging by

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incorporating a few MCQs after each section, enabling students to assess their understanding and thereby improve comprehension of the covered content. The study strongly recommends PowerPoint narrations with embedded quizzes, which reported an overwhelming response from the students. The PPTs were made engaging by simply adding a few MCQs to check their understanding, thus comprehending the content after one section.

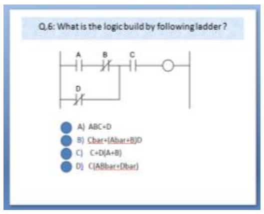
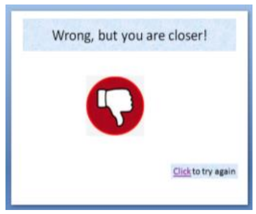
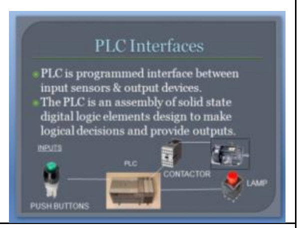


Fig. 3(a) Multiple Choice Question



(b) After a wrong response by the student

(c) After the correct response by the student



(d) Proceed to the Next Section

Non-graded questions were added after each section to improve student understanding. As shown in fig.3(a), the question is displayed in the PPT with four options, whereas option D is correct. For all three other wrong options, the slide in fig.3 (b) is displayed with a button to retry the attempt. This will continue until the correct choice is opted. As shown in fig. 3(c), after the correct answer, the learner is driven to the next section. This effort, though minimal, was positively received by the students.

IV. MULTIFUNCTIONAL AND FLEXIBLE SETUP IN A LABORATORY TO ATTAIN EXPERIMENT LEARNING OBJECTIVES (ELOS)

A. Need for flexible laboratories to satisfy learning of multifaceted aspects while experiments

The efforts reported by Karen et.al. (1999), about the learning experience in laboratories are noteworthy. The proposed apparatus (heat exchangers) is designed with good flexibility. It can test the performance of a single, two or three heat exchangers, and also two or three series and parallel configurations Such setup will undoubtedly provide students with experience ranging from demonstrations to hands-on design projects..

In recent years, engineering faculty has increasingly been recognized for their research contributions. Many in the engineering community argue that this trend has shifted focus away from the labor-intensive task of developing and improving instructional laboratories, which often receive no direct recognition. It is the question of how universities will alter the reward system for contributing to innovative laboratory development. Such learning platforms will also imbibe the research culture in engineering graduates. A step ahead, emerging economy firms (EEFs) have taken the R&D projects, keeping the goal to enhance technological capabilities in Stephen Bernat et.al. (2017). A special pilot course enrolled students to develop and start up an Automatic Data Collection laboratory. It reported the motivating results to reduce the start-up time from an estimated 18 months to 14 weeks in Bidanda et.al. (1995) .

The traditional laboratories probably will only validate and practice the known theories that are planned in the curriculum. It is indisputably a very primitive requirement. However, the engineering graduate has to serve the industry and research. As a result, it is now necessary to offer learners as much of a flexible platform as possible so that they can find the scope for design, evaluate a new device, or discover a new addition to our knowledge of the world. Fixed experimental setups limit learning and only allow validation of a narrow range of concepts. The aspiration of creativity in the budding technocrats will never be served. The flexible setup will also address the important performance indicators (PIs) defined in Programme Outcome. The most relevant PIs for the experimental learning are discussed in Section V.

B. The way to enhance the effectiveness of the laboratory through thoughtful development

The undertaking proposes the flexibilities and scope to extend the experiments to different aspects of the particular domain while developing the laboratory setup. The primary steps are listed below:

1. The experiments listed in the curriculum are used as the seeding reference.
2. Give thought to sorting out the concepts around the particular practical, which will add to knowledge and also the scope of analysis and creativity.
3. Identify the innovations that will help to modify the setup to extend the analysis.

At this stage of discussion, it's essential to explain with examples.

Example 1 (Heat Engineering): To predict the overall heat transfer coefficient for different heat exchangers given the flow rates of water and air.
Flexibilities expected: To analyze a combination of heat exchangers in series or parallel configurations
Solutions: By adding valves at the correct positions in the flow path, the heat exchangers can be configured in series or parallel as required.
Learning enhancement: In cascading configuration, there will also be heat losses from the Tygon™ tubes, which may or may not be considered. So it is possible to analyze the experimental outcomes to simplify the assumptions to predict the closest outcomes. So it is possible to analyze the experimental

outcomes to simplify the assumptions to predict the closest outcomes.

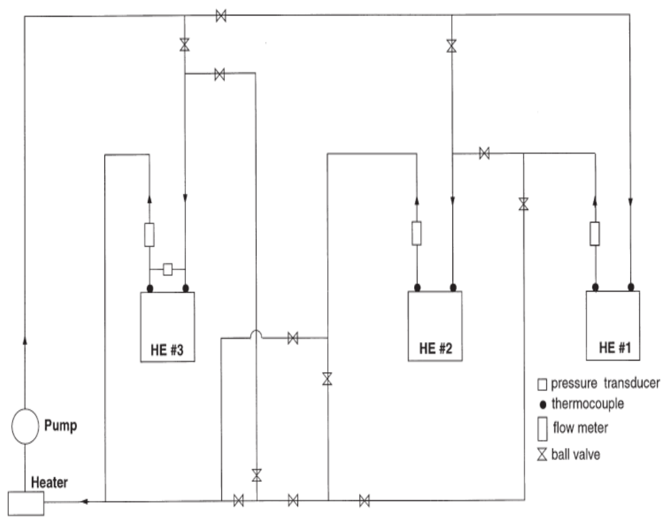


Fig. 4. Flexible Heat Exchanger Setup in Thermal Engineering

The flexibility of the apparatus for multiple configurations allows the investigation of both series and parallel operation. These configurations can also produce varied flow rates in the lines, demonstrating the effect of mass flow rate on the amount of energy transferred. The apparatus can also be used to demonstrate or test calculations of multiple pipe networks, a subject covered in most fluid mechanics courses.

The apparatus's adaptability to various configurations enables the study of both parallel and series operation. These arrangements can also result in different flow rates in the lines, showing how the mass flow rate affects the energy transfer. Additionally, the device can be used to test or illustrate calculations of many pipe networks, a topic that is taught in the majority of fluid mechanics courses.

These flexibilities are possible just due to addition of the valves at the appropriate flow path.

Example 2: Flexible setup in soil engineering

In civil engineering, a flexible dynamics lab for granular flow research is suggested in (T Heinze 2020). It is necessary to conduct laboratory-scale experimental studies of granular flow to characterize flow dynamics and create suitable mathematical and numerical models.

Protective measures against hazardous granular flow are usually solid obstacles aiming to reduce the acceleration of the moving mass and its momentum. Large metal nets are well known along roads and train tracks, preventing the mass to fall or slide onto the roads or tracks (Margreth S 2007).

Solid barriers are typically used as protective measures against dangerous granular flow to lessen the momentum and acceleration of the moving mass. Roads and train tracks are lined with large metal netting to keep the bulk from falling or sliding onto them (Margreth 2007). Several defensive structures are designed to guide a granular mass flow, lessen the quantity of mass involved, or slow down its acceleration rather than halt it. It is typically necessary to either build new laboratory setups for each test or do a laborious reconstruction to evaluate numerous situations and parameter variations.

A highly flexible, quick, and modular laboratory setup is portrayed using LEGO bricks. LEGO is a renowned Danish brand for kid toys using different binding blocks. Consequently, constructing a channel for granular flow experiments emerged as the least expensive option for this project. The experimental setup can be designed quickly and in a nearly limitless number of ways by connecting a variety of bricks and fixtures. This setup offers a variation of parameters such as slope length, channel width, height and shape, inclination, bed friction, obstacle position and shape, even density, composition, amount and grain size of flowing mass, and flow type. This experiment offers outcomes with observable quantities such as flow height, flow path, and flow velocity, and even run-out distance, size, and shape of the deposited material.

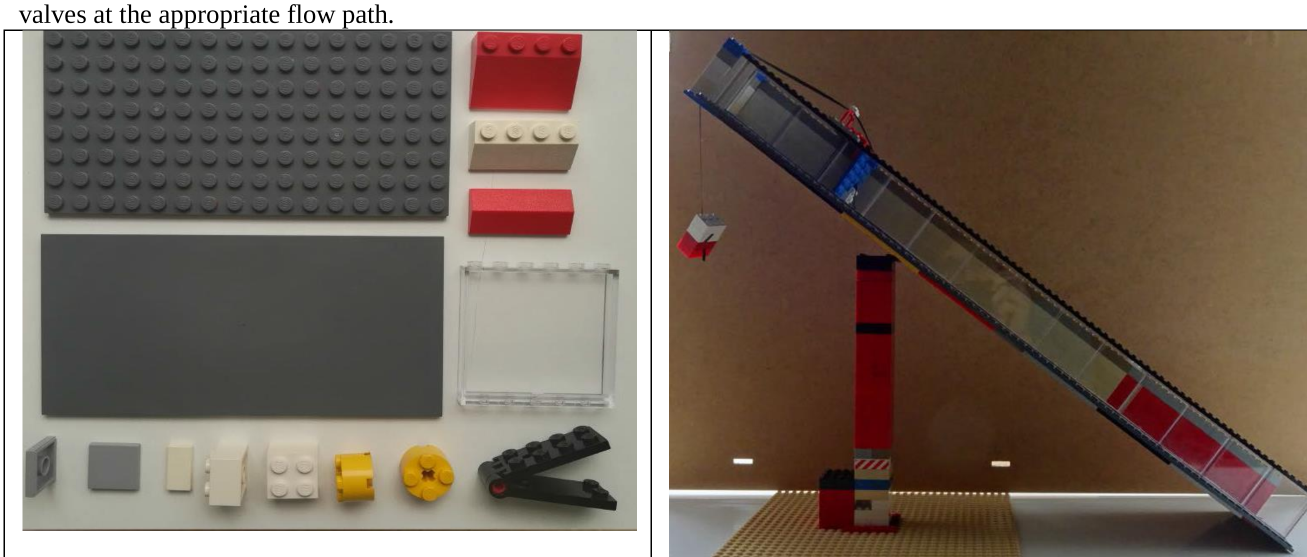


Fig. 5(a) Used LEGO bricks (b) Release mechanism

Example 3: Study of the frequency response of an Amplifier

Flexibilities expected: 1. Can we find the effect of various capacitors like input and output coupling Capacitors (C_{in} and C_{out}), Emitter bypass capacitors (C_E)

Solution: Simply make a provision to connect or disconnect them through a jumper with the option to select multiple values of capacitors.

Learning enhancement: Effect of $C_{in,}$ C_{out} and C_E on Gain and Bandwidth

Example 4: To compare the implementation of real-time applications on CPLD and FPGA boards.

Flexibility expected: Possibility to test the performance on a variety of boards like Virtex, Spartan III or Cool-Runner.

Solution: It is recommended to develop a universal board with add- on facility of various desired boards (Vertex, Spartan III or Cool-Runner) as a daughterboard.

Learning enhancement: The need for developing some application on a different kind of board as per the need of project like speed, power consumption, capacity to develop big project etc.

V. A Case Study: Programmable And Controller And Automation Laboratory

Programmable Logic Controller and Automation Laboratory is a costly affair that is mainly incorporated into the curricula of Electrical Engineering and Electronics Engineering. Case studies such as coin counters, bottle-filling plants, and AC motor drives are available in the laboratory. However, the setups in most of the departments at the university are fixed and hard-wired. The learning values of the setup are questionable as there is no scope for modification, and it merely satisfies the purpose of observation of a fixed application. While surveying these laboratories, the examples of identified reasons are also listed that have limited the learning experience in these setups.

1. The mechanical assembly in the applications has limitations to alter for experimenting with various possibilities.
2. The ports on PLCs are delicate and, therefore, are not recommended to be kept accessible to students, as there is a risk of damaging the setup during trial-and-error for innovative application. Hence, they are fix-wired according to the application.
3. The different alternatives of sensors, input switches, and outputs are not possible to make available on board.
4. The alternatives for different communication protocols are not possible, only one of them is used for a particular application.

A. A thoughtful, flexible design of the PLC setup

The undertaking explores the flexible design of the PLC panel, which is a direct contribution to this undertaking. The different sections on the PLC panel are labeled as shown in fig.6 and described for the provision and flexibilities/ learning scope in this domain.

1. Push Buttons: Eight push-buttons which are internally powered by +24 V making one terminal common in all switches, and the other terminals are brought to the left row at label 3.
2. Toggle switches: Eight numbers of toggle switches are internally powered by +24 V making one terminal common in all switches, and other terminals are brought to the left row aligned correspondingly at label 3.
3. Open terminal post are available to connect switch inputs further to the digital input channels of PLC. Channel X0 to X7 is used for the push button and X10 to X17 for toggle switches. The ports are brought at the terminal posts, saving the delicate pins of ports from damage by frequent mishandling.

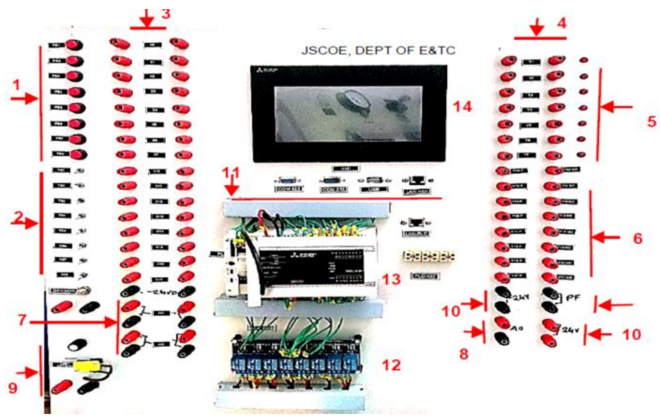


Fig. 6. The PLC setup design to offer flexibility

Flexibility: This arrangement makes it possible to select a variable number of pushbuttons and toggle switches as per the need of applications. Even it is possible to replace the push-button by a toggle switch just by changing the external banana connectors.

Learning value: The input channels are isolated; hence, some other types of switches are also possible to connect, bypassing the available switches from the panel. It will make possible to connect any type of switches or sensors e.g., make-break floating switch in the water level controller.

4. Open terminal post for digital outputs from PLC.
5. The PLC output channels (Y0 to Y7) can be connected to commonly used LED indicators using jumper connections.

Flexibility: However, the other kind of indicators also can be connected.

Learning value: The setup doesn't restrict the need for some special need of indicators eg. Pilot lamps or LEDs of different colours like those used in traffic signal controllers.

6. These are the NO contacts of relay outputs (Y10 to Y17) which are the charge-free contacts. The

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corresponding terminal posts on the left correspond to terminal posts of NO contacts which can be connected to any load by extending through banana jumpers on right side.

Flexibility: Any kind of actuators like motors solenoids etc. also can be connected.

Learning value: The poles of relays can be energized by any voltage externally applied to the output device which makes it possible to develop almost any kind of real-time project.

7 & 8. Analog inputs: Two sets of analog input and output are made available on the board. It is based on the counting pulses to get a digital count corresponding to analog input value.

Flexibility: Two terminals are spare to expand the analog channels by add-on analog modules if required.

9. Special input devices: The potentiometer analog input, proximity switch, limit switch to be connected to the left side of the terminal post labelled by no. 7 which is further passed to the PLC analog channel by shorting the corresponding terminal post.

Flexibility: The potentiometer is available on the board or some other analog input. The proximity switch available on the board or some other type also can be used.

Learning value: potentiometer available on the board explores the function of analog inputs or this learning will also extend the use of analog inputs like encoder pulses. The proximity sensors are available as NPN or PNP types can be connected and used in the applications.

10. The supply terminals are +24V and 0V.

Flexibility: The supply can be used for external devices which are selectively connected to +24 V and 0V.

Learning value: The interface of the sink and source type of sensor is very clearly understood.
11. The extended ports from PLC to the panel for the different protocols like Ethernet to PLC and HMI, COM232, USB and COM 422.
Advantage: this small change made the hesitation free permission and use protecting the direct handling of any delicate ports on PLC and HMI
12. Terminal posts
13. PLC FX5U
14. HMI

This way, the designed panel of the PLC is now a fully flexible learning platform that motivates the student to build any real-time application rather than a mere "black box." *Sample applications developed by the students taking advantage of flexible setup are documented in detail (Annexure A) for learners of Electronics courses.* The flexible setup made it possible to develop various real time applications like logic gates, VFD control, Barcode scanners, traffic light controllers, water level control, etc. Examples of different experiments implemented using the same setup discussed above.

The flexible lab setup makes possible to get extended insight into experiments. For instance, the fix setup could experiment to measure parameters for one heat exchanger while flexible setup can use series parallel connections of heat exchanger variation in flow etc. It will obviously train the graduates to address open ended problems in the industry and also for further education. A full-proof design of the flexible laboratories may incur high initial cost for research and development in some cases which further reduces abruptly for producing more number of similar setups.

VI. Other Approaches Of Laboratories

OBE is a systematic framework for evaluating and fostering intellectual growth. It enables teachers to create learning goals that advance from simple knowledge recall to more intricate analysis, synthesis, and evaluation, guaranteeing that students can use information in more complex ways across various topics and contexts. The work explores different kinds of laboratories like flexible setup, conduction videos and relevant documents on QR, Open ended problem statements for Laboratory Experiments, Networking Environment in the Lab, use of AR/VR laboratories etc. It obviously develops the students at different levels like the Cognitive domain Affective domain and psychomotor domain.

A. Networking Environment in the Lab:

During lab sessions, a networked environment can provide instant access to data, and the instructor can make resources available to all students at the same time. Centralized management and tracking of the work completed at each bench is made possible by the laboratory's networked architecture (Jiménez-Leube 2001).

B. Open ended problem statements for Laboratory Experiments:

The researcher shared experiences from open-ended experiments through selected case studies.. The case offered an open-ended problem statement in the concrete laboratory to students already doing the traditional laboratory course study. Students demonstrated initiative and ingenuity by creating many solutions to the challenge (Zaiton Haron 2013).
Limitation: Although the method provides a thorough comprehension of the subject, the difficulty level prevents most average students from participating.

C. Project-Based learning approach in Laboratory:

The design and assessment of a mechatronics system using problem-based learning (PBL) is explained in [b]. The implementation process involved the identification of real-world problems pertinent to mechatronics engineering. Students analyze case studies and examples such as the smart wheelchair, piezoelectric brake, photovoltaic system, unmanned aerial vehicle (UAV), Autonomous mobile robot, and collaborative robots (cobots) to understand the design methodology of VDI2206 framework. The learning objectives of this system were to improve the comprehension of mechatronics system design concepts, the ability to analyze complex systems, and the practical relevance of theoretical knowledge (Vinayak 2024).

D. PLC practical learning using Virtual Reality platform

The article (Kubola 2022) demonstrates a highly excellent laboratory setup that integrates Information Technology and classic automation technology by Automation 4.0 technologies. The undertaking illustrates a learning environment for PLC practical learning activities using Virtual Reality technology in the framework of the ETAT Erasmus+ project.

The proposed system uses two main sections: the computer with the virtual reality devices and the VR Learning System for PLC. HTC Vive CE 2018 is used out-port on the graphic card which includes VR glasses, base stations, and controllers.

The second part is to develop 3D models (fig.7) used in the virtual environment. It mimics the real equipment and functionality for the training. Blender is used for 3D model creation, whereas the Unity is used to create interactions and behaviors of the objects. All the developed elements are then connected over the platform called SteamVR.

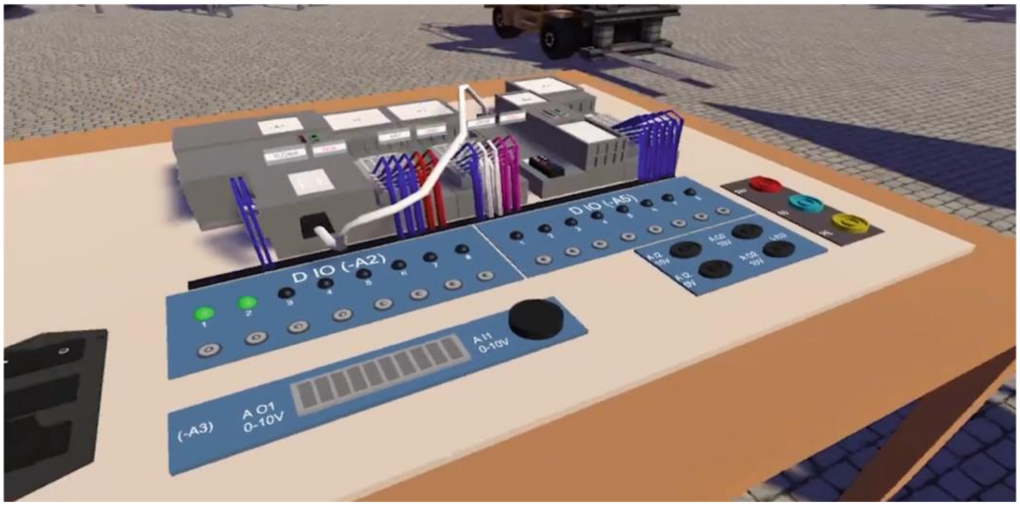


Fig.7. The 3D model of PLC next in virtual environment

Although the proposed system sounds very fantastic, its versatility diminishes due to the following reasons:

- The system is a single-user system where the batch size of students is a minimum of 12.
- The cost of VR accessories and software is high and the initial setup is cumbersome.
- Moreover, the core learning of the actual lab course will be scribbled due to the overhead of learning the VR setup.

E. Laboratory using Augmented Reality

The laboratory application for Chemistry lab using Augmented Reality is presented in (Tuli, N. 2015). Traditionally, in a chemistry lab, only prescribes set of experiments are to be performed using step by step procedure in lab manual. If the student wishes to learn beyond the scope of the experiment, usually would have to rely on teacher. Students face potential risk of using wrong chemicals while performing lab experiments. Unless their curiosity is satisfied, creating interest is difficult. To overcome this problem, augmented reality just augments some virtual information on top of the real world. It preserves the user's sense of being in a real world in contrast to Virtual reality setup. .

Students are taking the chemical in a test tube and scanning the apparatus marker containing the desired element through the camera. We would have all the elements/chemicals labeled with markers.(Markers are 2D patterns like barcode).This will display the properties of that element on his screen. Suppose student brings test-tube containing a chemical marker in front of the tablet , the properties of potassium iodide. (Fig.8 a) and lead nitrate (Fig. 8b) are displayed on screen.

Fig. 8a. Scanning test tube with potassium iodide

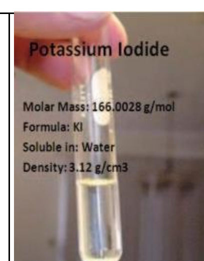


Fig. 8b. Scanning test tube with potassium nitrate

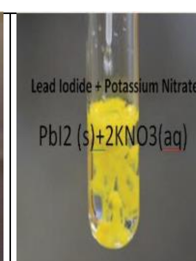


Fig. 8c. Resulting Reaction displayed

Likewise, if someone wishes to know how one element reacts with another, he only needs to scan two pieces of equipment that contain the various elements; the AR gadget will show the elements' reaction results.

If he scans both test-tubes containing potassium iodide and lead nitrate together he will see the resulting reaction. (Fig.8c), If the user is trying to react two elements that are risky to react then the message of “RISKYREACTION” would be displayed on the screen.

The recent studies like use of Augmented Reality/Virtul Reality laboratories give more scope to the learning which strengthens the platform for students' careers and further education.

VII. OUTCOME BASED EDUCATION

A. Program Outcomes defined by NBA

After the establishment of ample Engineering colleges in India, the move to impart quality engineering education started. The National Board of Accreditation (NBA) was established by the All India Council for Technical Education (AICTE) in 1994 and operated as an autonomous body since 2010. In 2014 it was granted full membership status in the Washington Accord discussed in Stephen Bernat et.al. (2017).

NBA had published the learning outcomes (also known as Program outcomes abbreviated as PO). The POs are the statements regarding the graduate attributes that are expected to be imbibed after completion of the course as postulated by Grinter et al. (1995). They are summarized below:

1. Acquire engineering knowledge mainly to address complex engineering problems.
2. Analyze engineering problems to arrive at a sustainable solution.
3. Design solutions for complex engineering problems considering the public health and safety, and societal and environmental considerations.
4. Investigations using research-based knowledge which includes the design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. Apply the way of thinking educated by the contextual knowledge to assess societal, health, safety, legal and cultural issues.
7. Professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. Ethics: Apply professional ethics and norms/standards of the engineering practice
9. Effective functioning as an individual, and as a member or leader in teams, and in multidisciplinary fields.
10. Comprehend and write effective reports documentation, communicate in the form of presentations, and give and receive clear instructions.
11. A sense of Project management and finance.
12. Life-long learning.

These POs are satisfied through the theory sessions as well as Laboratory work. Moreover, there are more chances to attain most of the skill-based POs through a laboratory.

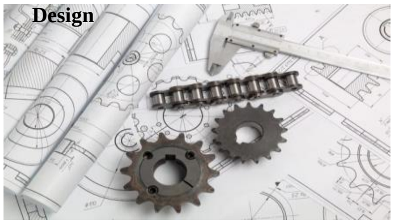
B. The laboratory-intensive POs and attainment through effective laboratory

From the perspective of laboratory work, the POs defining the following skills are imparted to a large extent.

1. Design
2. Investigations provide valid conclusions.
3. Modern tool usage to Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools which are expected to inculcate the ability to predict and understand the limitations of different solutions.
4. Professional engineering solutions for sustainable development by trying different alternatives.
5. Effective functioning as an individual and as a member or leader in teams, and multidisciplinary fields by taking innovative problem statements.
6. Comprehend and write effective reports documentation, communicate in the form of presentations, and give and receive clear instructions.
7. A sense of Project management and finance.
8. Ethics: Apply professional ethics and norms/standards of the engineering practice
9. Effective functioning as an individual, and as a member or leader in teams, and in multidisciplinary fields.
10. Comprehend and write effective reports documentation, communicate in the form of presentations, and give and receive clear instructions.
11. A sense of Project management and finance.
12. Life-long learning.

These POs are satisfied through the theory sessions as well as Laboratory work. Moreover, there are more chances to attain most of the skill-based POs through a laboratory.

TABLE I
PROMINENT COMPETENCIES AND PERFORMANCE INDICATORS ADDRESSED DUE TO FLEXIBLE LABORATORY SETUP

Program Outcome	Key Feature	Traditional laboratory	flexible laboratory
	Scope to extend the problem statement	limited due to fixed problem statements	Enhanced
	Insights for different Alternatives	Difficult to explore the effect of the different alternatives.	Possible to explore the effect of the different alternatives
	Investigating alternatives	Less or no scope for exercising alternatives	Sustainable solutions are the best possible after trying alternatives
Working in team 	Innovative problem statements	Minimum team work while working on fixed path	The teamwork and discussion on solutions enhance by taking innovative problem statements
	Involvement of the student	finding the limited literature for known & limited problem statement	finding the relevant literature more for innovation

Moreover, there are some objectives that are implicit expectations from the stated POs: Learning from Failure, Creativity to address a real-world problem, Psychomotor which deals with the competency of selection, modification, and operation of appropriate engineering tools and resources.

Journal of Engineering Education Transformations, Volume 39, No 3, January 2026, ISSN 2349-2473, eISSN 2394-1707

The comparison between the traditional and flexible Laboratories because of attainment of POs is shown in Table I.

VIII. RESULTS

A. Systems developed as a evidence to the design versatility due to flexible design of the PLC setup

Jain, et.al. (2020) suggests Improvement of course outcome with the help of changes in laboratory experiments. In the following discussion, the two real life applications are demonstrated to understand the benefit of flexible setup developed in this undertaking while developing the new application.

1) Water level controller

Problem Statement: The pump should get ON when the RESERVOIR consist of sufficient water and lower level (LL) of the OVERHEAD tank is empty. When the level is attained to the position of the higher sensor (HL), the pump should get off and maintain off state until the level again doesn't drop below HL (refer to fig.9) for sensor connections to PLC and fig. 10 for the physical setup of tank and sensors.

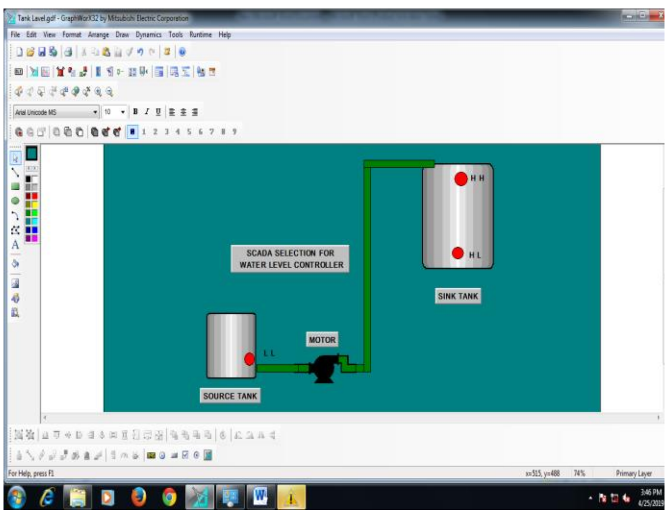


Fig. 9. SCADA screen for water level Controller

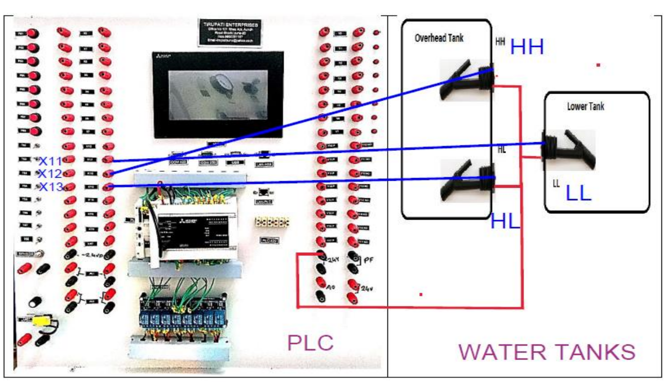


Fig. 10. Complete connection diagrams for Water level Controller

Experiment learning outcome (ELO)

1. The required functionality is simulated correctly according to the truth- table.
2. The utilization of available I/P sensors (eg. NO or NC switches here) is possible through ladder programming.
3. The resources namely hardware Datasheets of FX5U and Sensor/Driver is sufficient to implement any of the automation systems. The function is proved to be executed for real-time execution.
4. HMI screen indicates the real-time status of I/O and also control action from the HMI screen is verified
5. SCADA screen also actualizes the real-time status of I/O which is meant for remote monitoring. HMI screen indicates the real-time status of I/O and also control action from the HMI screen is verified
6. SCADA screen also actualizes the real-time status of I/O which is meant for remote monitoring.

The design of Water level controller system is explained in detail in Annexure to address methodology.

2) Traffic Signal Controller

Problem statement: Implement the controlling of Traffic Lights in PLC using Ladder Diagram programming language. Two roads cross each other and two lamp-heads are installed with lamps R1 Y1 G1 for Road-1 and lamps R2 Y2 G2 for Road-2 as shown in fig. 11(a). After pressing the start button, the Road-1 signal should be permitted (GO/GREEN) for 50 sec followed by yellow (WAIT) for 20 seconds. And cycle should repeat as shown in fig.7(b).The system may be stopped in case of an abnormal situation with the STOP switch.

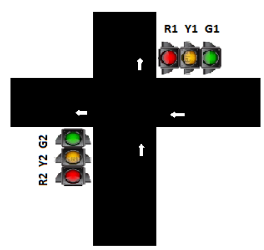


Fig. 11(a) Setup for Traffic Controller

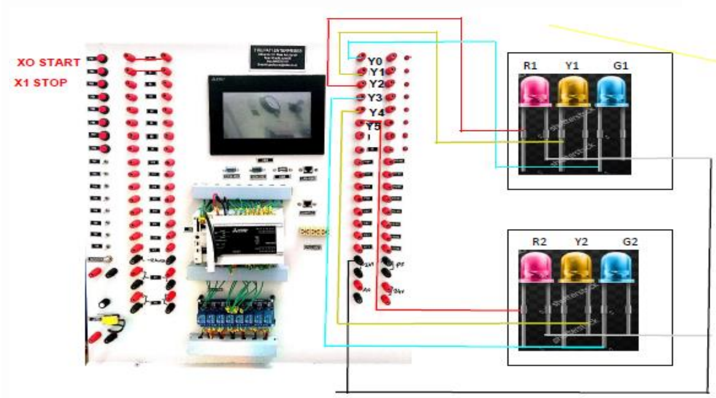


Fig. 12. Complete connection diagram for Traffic signal controller

Journal of Engineering Education Transformations, Volume 39, No 3, January 2026, ISSN 2349-2473, eISSN 2394-1707

SM0= System health bit; X1= Start bit; X2= Stop bit; T1= First delay timer T2= Second delay timer; T3= third delay timer ; T4= third delay timer used for others M0= latch bit; Y0= Green 1; Y1= Yellow Y2= Red 1 Y3= Green 2; Y4= Yellow 2 ; Y5= Red2;

B. Survey

The 47 recipients were involved in the study at Jayawantrao Sawant College of Engineering, Pune, India. By the end of March 2020, the course had been imitated using the e-learning approach. Following a week of instruction, the knowledge gained by the students was checked by assessment tools like tests, multiple-choice questions (MCQ), and assignments. After completion of the course, a well-crafted Google survey was given to collect the inputs. The purpose of the review was to confirm that the various tools and strategies employed in the course were successful and widely accepted. For each question, there were three possible grades: significant, moderate, and low. The corresponding marks for each level were 3, 2, and 1, respectively.

The students were urged to express their sincere opinions. The same feedback form was repeated after some duration to discard the non-thoughtful responses. This elimination used the correlation between two responses from the particular student. Two Google forms of the same students filled at different times showing a correlation value of more than 0.75 are only considered. Only three students have given the non-correlated feedback, hence discarded.

Table 2 displays the percentage of responses recorded by the 44 students to the questionnaire about the various tools and techniques. The rate of feedback is the aggregate vote for particular tools or approaches. The study also investigated the difference of opinions among the students by using Standard deviation which is calculated from the responses of all the students to the same questions. The high value of feedback along with the low deviation among the number of participants enhances the level of confidence to choose suitable practices. . The confidence level in choosing suitable practices is increased by the high feedback value and the low response variation among the participants.

TABLE II
Student feedback for the approaches used in laboratory **instructions**

Sr. No.	The learning resources, adopted teaching technique/tool	% feedback	Std. Deviation among the responses to the same questions
1	Study material ,Videos on QR code	92.6	0.545
2	Use of Simulation software /Animated systems	93.8	0.505
3	Power-point narrations with embedded quizzes	87.7	0.694
4	Use of virtual Labs	64.7	0.639
5	Flexible setup for creative learning	96.8	0.825

While the feedback for all other approaches to enjoyable and in-depth learning in the lab is overwhelming, the choice for a virtual lab by the students is less. Hence, we recommend the virtual labs for the demo experiments with ease of modification. Convenient freeware for PLC simulation with animated case studies is available. Nonetheless, particularly for PLC labs, the following shortcomings that diminished the feedback were reported by the students.

1. Virtual labs need the internet and can't do anything offline.
2. Every virtual lab follows different procedures of operation, nomenclature, and symbols.
3. Some virtual labs may require some add-ons and impose system requirements.
4. Many virtual labs developed experiments common to electrical, electronic, and instrumentation courses, but with different outcomes. Hence, it is cumbersome to find the experiment with the desired orientation relevant to the particular course.

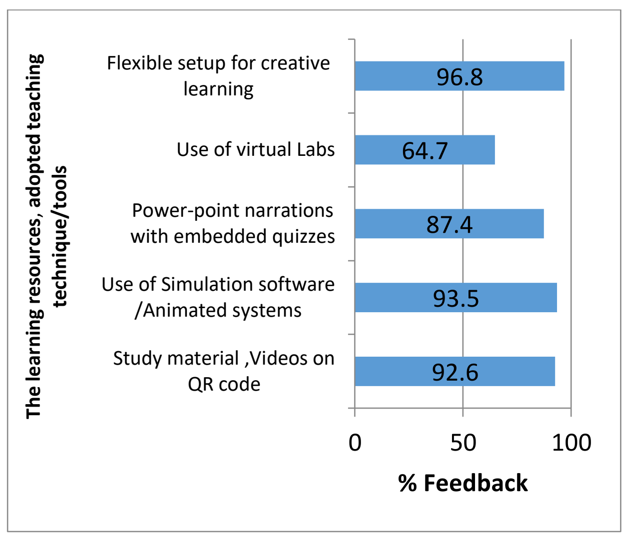


Fig. 13. Student feedback

The research presents various tools for comprehensive and straightforward learning, including flexible laboratories. These considered provisions undoubtedly enhance the learning experience. Although cross-sectional studies constrain the ability to establish causal links, it is the sole approach for this investigation.

Firstly, education also relies on psychological aspects. Thus, the primary focus of the study is whether students in the specified course appreciate the efforts made. This research does not aim to establish causal relationships but instead seeks to identify connections between efforts and student adaptation. Nevertheless, excluding casual responses improves the confidence intervals, as the most variable feedback from the same individual at different times is omitted using standard deviation. This research could serve as a foundational reference in a cohort study.

Conclusions

The innovative efforts to develop flexible and innovative laboratories have greatly influenced Outcome-Based Education (OBE). They have the full potential to design, investigate alternative sustainable solutions, and create real-time applications. The POs are satisfied substantially through traditional laboratories; some of them would have a rare scope to fulfill. A case study of PLC & Automation Laboratory explores how the minor thoughtful arrangements in the setup make it a versatile learning platform with almost no boundaries for creativity.

The automation applications to address the real-time problem are proving the facts sufficiently. The additional competencies are found to be inculcated in the students through the rarely addressed performance indicators (PIs) during laboratory work. After completing this course, students can develop micro-projects on their own, small but real-time applications like coffee vending machines, car parking systems, running only two furnaces out of three to avoid overloads, etc. There is scope to motivate the development of such laboratories if the assessment system includes credit for the task taken beyond the curriculum. Using QR codes, simulation/animations, and interactive quizzes reported the average students' feedback of 90.15% and 96.8 % for creative learning using a flexible setup.

As discussed earlier in the flexible heat exchanger experiment, a similar approach can be adopted in refrigeration engineering. Applications in which the refrigerator capacity requirement is variable, experiments can be conducted using multiple modular components—such as condensers, evaporators, and compressors which can be selectively coupled as per load requirement—instead of running the fixed and large-capacity unit. Likewise, the Civil Engineering department can explore the use of flexible or modular bricks and fixtures for constructing experimental setups. In the domain of product design, detachable components can be effectively utilized for rapid prototyping and iterative development of products.

The statement of conflict of interest:

All authors certify that we have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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It is worth noting that Dr. P. A. Patil, Principal of Jayawantrao Sawant College of Engineering, Hadapsar, and Prof. Sayyad T. D., Head of the Department of Civil Engineering, Jayawantrao Sawant Polytechnic, Hadapsar, Pune, contributed to the validation of the hypotheses in Mechanical and Civil Engineering, respectively.

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Journal of Engineering Education Transformations, Volume 39, No 3, January 2026, ISSN 2349-2473, eISSN 2394-1707

ANNEXTURE A:

Methodology and Design Details for sample student project (Water level Controller):
(*It is common for every project*)

1. Main screen of HMI with different buttons for various applications

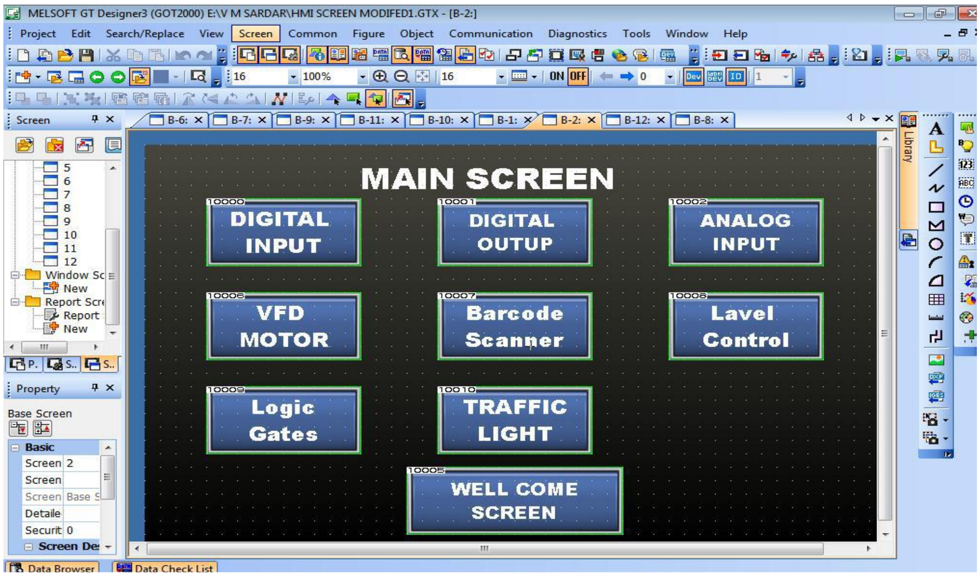


Fig. 1. Main HMI Screen with buttons of eight application

The Main screen shown above explores that the flexible setup made it possible to develop various real time applications like logic gates, VFD control, Barcode scanner, traffic light controller, Water level control etc. These buttons are designed using GTDesigner3 with mapping of real input outputs by device tags. The screen programme is further transferred to HMI. The HMI screen is touch screen and after pressing *Level Control* button on it, the next screen will be switched for displaying the real-time execution of the system.

A. Water level Controller

1. It is recommended to list out the Truth Table entries according to Logic required for the intended application. (

TRUTH TABLE: DESCRIBING THE OPERATION OF WATER LEVEL CONTROLLER

Sr. No.	PLC Status	Mains Status	I/Ps (Level Switches) and Status			Require O/P (Pump)
			X11 (LL)	X12 (HL)	X13(HH)	Y0
1				LOW	LOW	HIGH
2	SM400 bit is DONE which indicates the healthy status of PLC	X10 ON	HIGH	HIGH	LOW	HIGH
3				HIGH	HIGH	LOW
4				HIGH	LOW	LOW

2. Plan the organization of the required components in Ladder form sequences.
3. Drag and place the required components from library of GXWork.

Journal of Engineering Education Transformations, Volume 39, No 3, January 2026, ISSN 2349-2473, eISSN 2394-1707

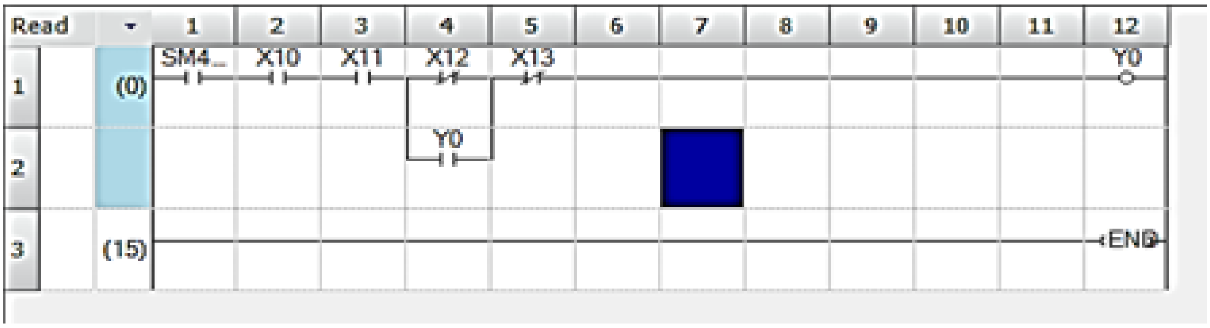


Fig. 2. Optimized Ladder diagram for Water Level controller

4. Run in offline Monitor mode to check functionality simulating I/Os and write to PLC.
5. Connect required I/Os and check the real-time execution referring interface manual .

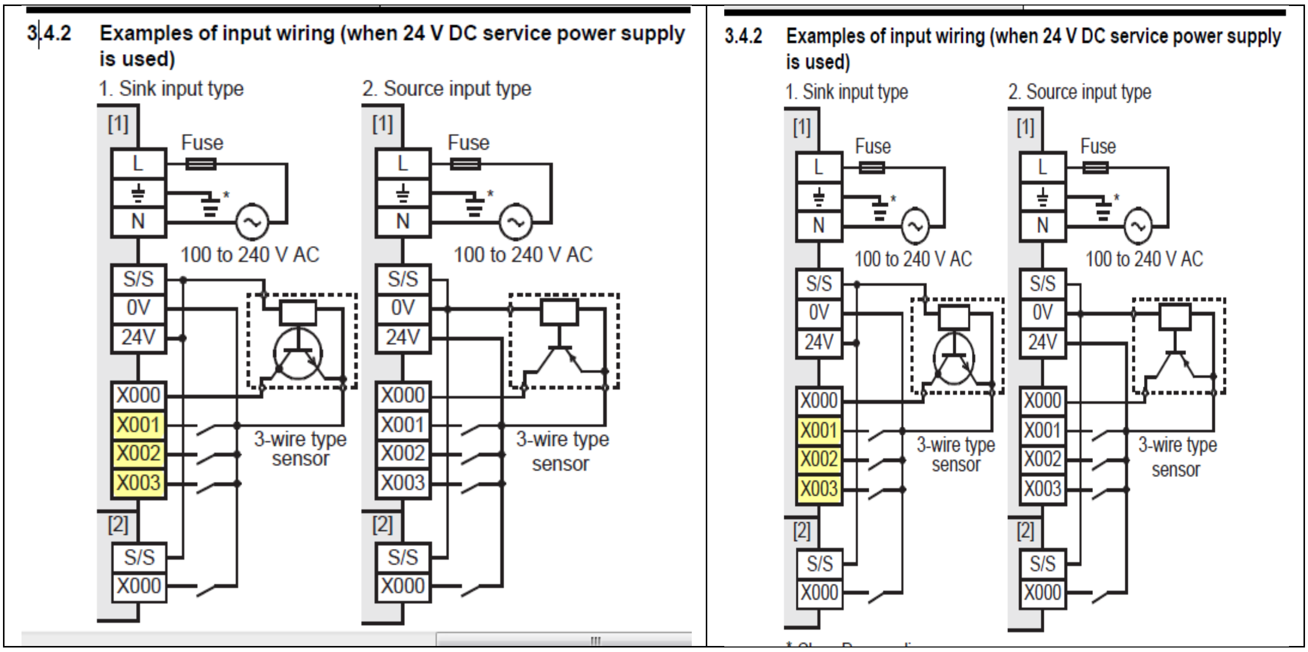


Fig. 3. The generic guidelines for Input and Output device connection

B. HMI Development GTDesigner3

(a) Bit switches are selected for inputs where the physical addresses are assigned manually same as selected in the ladder diagram. Eg. A input for motor start is assigned as X1000 as shown in figure 4.

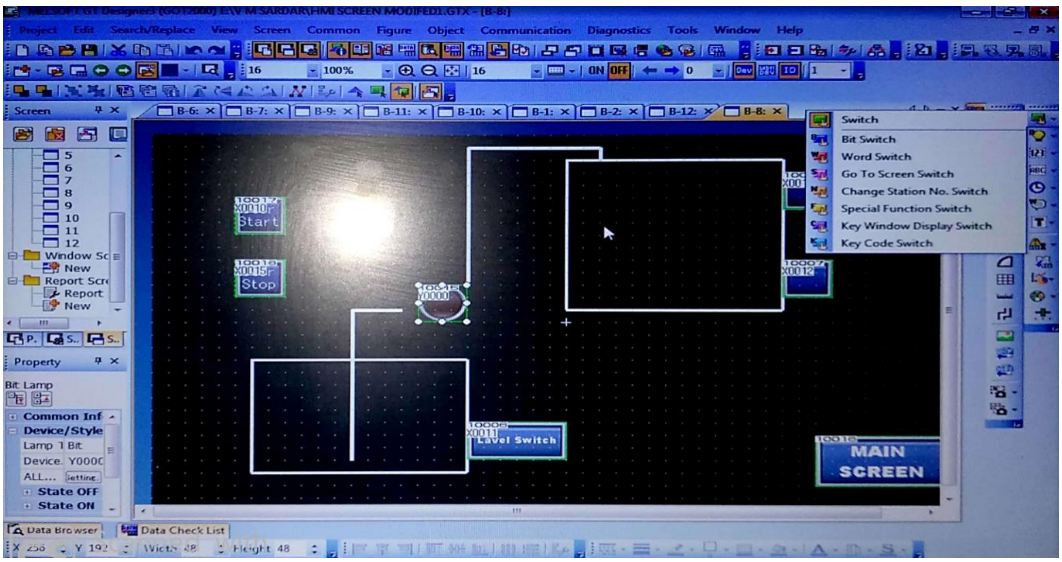


Fig. 4. Screen 2 Water Level Controller

(b) Similarly Bit Lamp or Word Lamp can be selected for output with address as Y0000 with the ON state and OFF state colour selection as shown in figure 5.

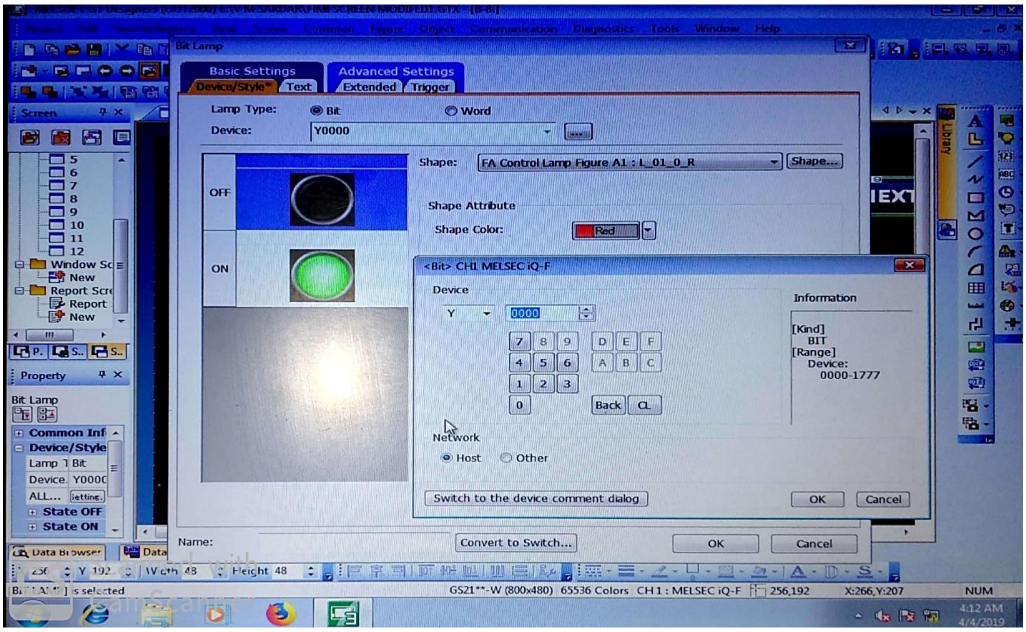
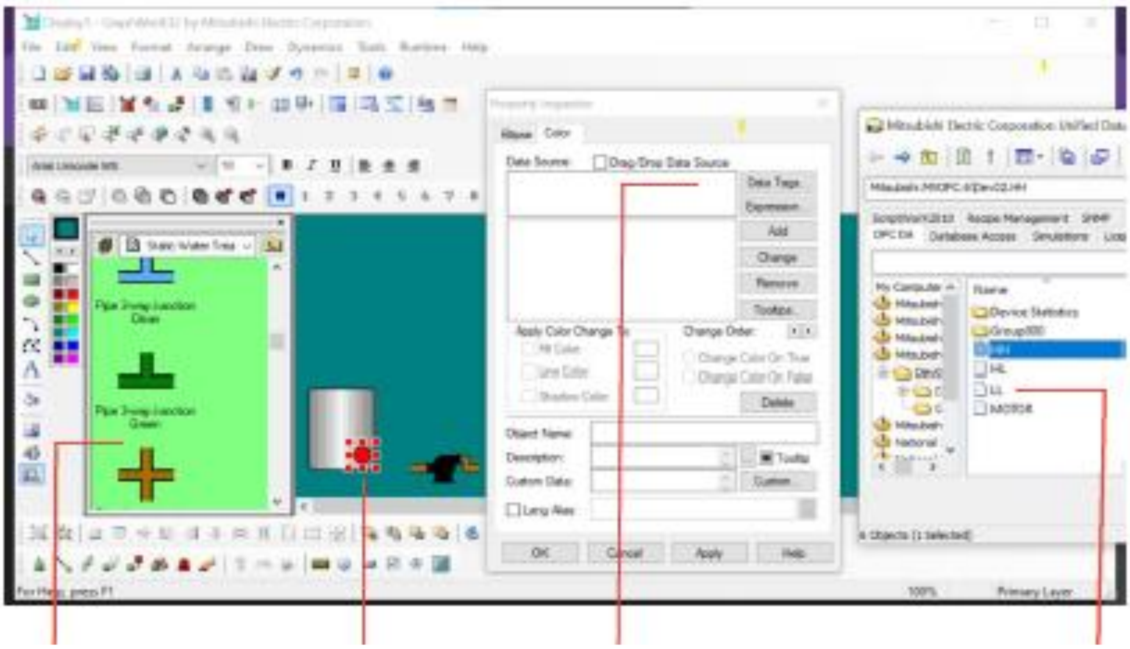


Fig. 5. Selection of Bit lamp for output with address selection and other attributes

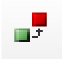
C. SCADA

- A SCADA tool developed by GRAPHWorx32 provides a workspace with a Drawing Library. Complete the design using components in the library with user labels, eg. Tanks, pumps, indicators, pipes etc.
- Now, switch to another Mitsubishi tool called OPE MX CONFIGURATOR to define the tags for interactive components, such as input sensors (X11, X12, X13) and output Y0 designated as MOTOR.
-

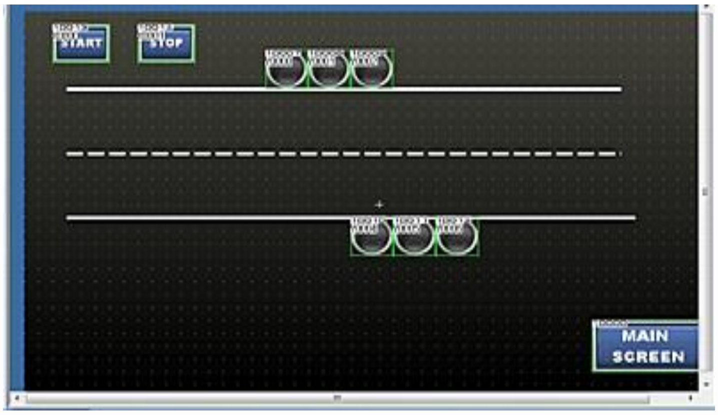


Component library **Components selected on workspace** **Assignment of tags with hardware** **Tags defined on OPE MX CONFIGURATOR**

Journal of Engineering Education Transformations, Volume 39, No 3, January 2026, ISSN 2349-2473, eISSN 2394-1707

- Switching back to GRAPHWorx32, SELECT OBJECT in figure (eg. X11 labelled as LL sensor here). Select the Color () switch seen at the bottom Ribbon and press **the Data Tags…** button to assign the tag to the physical hardware connected to that port.
- The SCADA will start mimicking the real-time process. Eg. if the lower tank is full, sensor X11(LL) turns GREEN, or else RED.
-

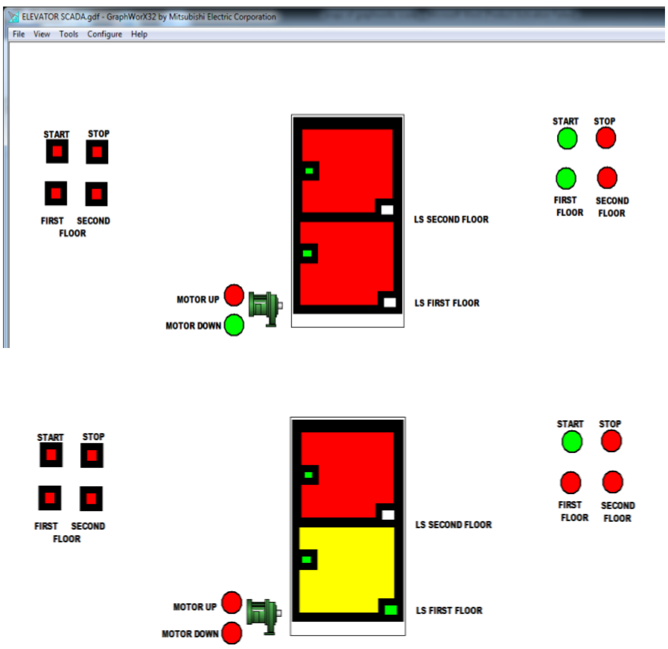
2. HMI screen for Traffic signal controller



3. Elevator System Controller:

Problem Statement: To design an Elevator system for a two-storey building following primitive functional and safety constraints like (i) the floor request should be latched till the completion of the request, (ii) not to allow serve the other floor request in between the first task is completed, (iii) not to start the lift unless the door is closed.

The setup is validated on the SCADA system as shown in fig.10. The SCADA implementation is validated using GraphWorkX32.



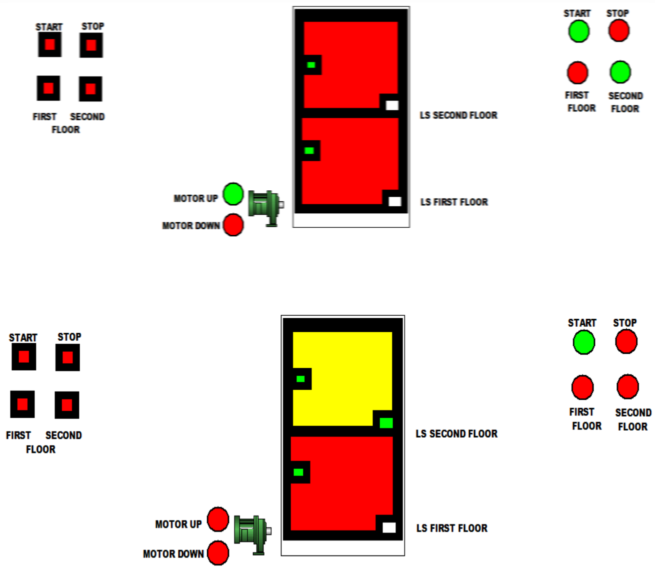


Fig.10. SCADA system for Elevator System Controller

4. Questionnaire used for Student Feedback

Q. Were you able to carry out the experiments in video provided via QR code without the lab assistant's supervision?
Q. Do simulations help you prepare at home and make it easy to experiment on actual setups in the lab?
Q. Does PowerPoint presentation make you understand the basics, and do quizzes test your understanding and memorize the key points?
Q. Did you find the virtual labs making you competent in procedure and creating the programming of different applications?
Q. As a result of flexible lab design, how many experiments have been conducted in a single setup?