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A Project-Based Learning Approach to Measurement Systems Laboratory for Undergraduate Students

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Abstract : Project-based learning (PBL) is one of the most effective teaching frameworks for undergraduate engineering courses due to its enormous advantages. The PBL approach facilitates active student engagement to a greater extent in laboratory courses as it can induce the process of complex and proactive thinking, problem-solving, and communication skills. This work presents pedagogical intervention in curriculum design and delivery of Measurement System Laboratory courses to undergraduate students in engineering. The study impacts assessing these new practices on student engagement and persistence in teaching-learning. The evaluation of student perception of the laboratory revealed that students enjoyed its execution, leading to improved academic performance and imbibing problem-solving skills. The PBL-laboratory exercise was a precursor to improvised student learning with self-directed initiatives working in teams. The study underlines excellent opportunities available through the reflection process that form the bedrock to strengthen their engineering laboratory practices. The detailed research strongly suggested PBL as the right way to engage students in the laboratory to fulfill curriculum needs.

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I. Introduction

Project-Based Learning is an interactive and powerful teaching method appropriate to laboratory courses introducing practical concepts. The often-stated line 'one ounce of practice is worth a pound of theory' strengthens the belief that laboratory courses offer greater scope to enhance the teaching-learning process. The PBL concepts are made to laboratory courses per se because of the flexibility to bring in an engaging experience less evident in theoretical discourse.

The educational delivery for practice-based classes requires a different type of thinking, as represented in Figure 1, highlighting PBL, an amalgamation of learning theory, practice, pedagogy, subject knowledge, context, and technology.

A typical laboratory course in an engineering program with ten experiments assigns different weights to each task, leading to preferential focus by the student.

The student concentrates more on studying readings based on practical investigation. The methodology adopted in teaching-learning must focus on capturing existing systems' knowledge or facilitating innovations into conceived designs. The

PBL encourages students to be involved in independent learning, peer interaction, and self-directed learning with a higher degree of self-motivation [1-3].

Figure 1 depicts PBL, which consists of linguistic context-rich theory integrated with technology-enabled practice segments to help learners adopt the hands-on method. The formulated problem statements help understand and guide any activities to explore the theory topic. It helps to identify what information is needed to solve the problem. Implementation of open-ended project activity was done at the end of the semester. Students used MATLAB software for simulation, which helps develop a hardware platform and engineering concepts for students [4-5].

The teaching-learning process comprises six steps: studying, selecting, planning, implementing, analyzing, and adjusting. Figure 2 shows the stages of exploring and identifying learning strategies, topic questions, outcomes, objectives, learning events, evaluation, and assessments.

The entire process requires adequate effort to grasp process execution and adapt to teaching and learning thoroughly. It supports reading, writing, listening, and speaking, facilitating student learning. Figure 2 shows the teaching-learning process involving higher-level learning aspects, including critical thinking, creativity, and scientific temper to continuous improvement in the laboratories.

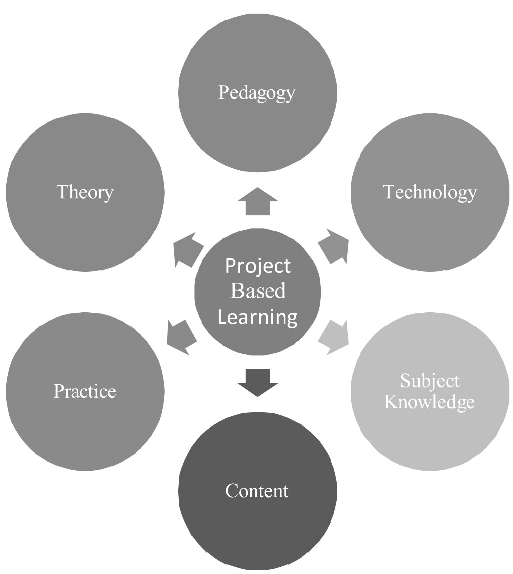


Fig. 1: Project-Based Learning Process

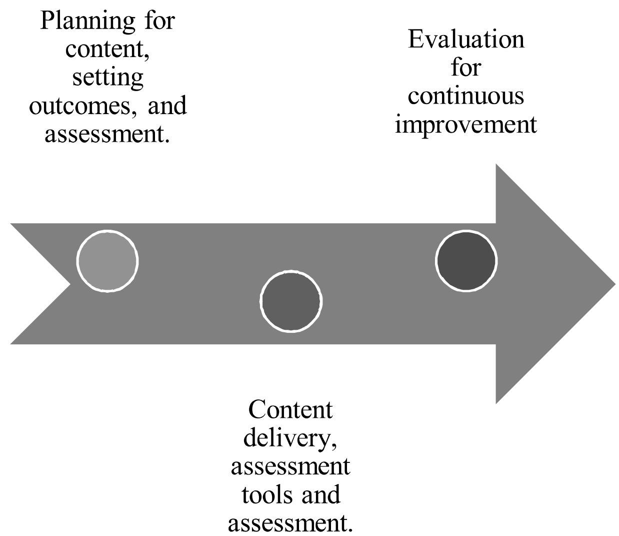


Fig. 2 : Teaching-Learning Process Cycle

The reported literature on pedagogical interventions in laboratory courses has shown considerable enhancement in active learning techniques. The adequately designed laboratory experiments enhance students' learning skills. They developed a contextual implementation framework for real-time measurement experiments in automation and robotics applications.

Tshai K.Y. et al. have briefed about quality control improvement (CQI) strategies in the education system using Programme Educational Objectives (PEOs) assessment criteria. Using PEO assessment criteria, students are satisfied with their achievements. These PEOs help students improve their attainment level as part of the CQI. The authors explained how to encourage students to adopt this process [6].

Tom Borsen et al. have presented different concepts and pedagogical methods in the educational trends and new challenges for ethics teaching. This paper has explained how to conceive, design, implement, and operate (CDIO) teaching ethics. The authors explained that the developed design implement operate (CDIO) method is an active learning pedagogy. It is closer to the real life of the scientist or engineers. This method helps students build resources, group work, and make collective decisions in the Project-Based Learning activity [7].

Atasi Mohanty et al. focused on the Indian engineering and professional education scenario, global issues, and current needs. The authors have explained how to promote partnerships between private and public sectors and increase the scope of engineering apprenticeship training in the service sector. Taylor B. et al. have presented how to understand, identify, classify, and describe the performance of components through modeling techniques and MATLAB analytical methods. The National Instruments Labview software for the MyDAQ data acquisition module for real-time hardware control was recommended [8-10].

3. Research Contextual Framework

In India, Engineering Institutes have set a standard grade scale for assessing students, including letter grades- S, A, B, C, D, E, and F, decreasing performance. Alternatively, student performance can also be gauged through outcome-based indicators in the context of new active teaching-learning approaches such as outcome-based, project-based, or problem-based learning.

Outcome-based teaching-learning represents a unique methodology of student-centric knowledge dissemination aiming at higher student achievements, focusing on imbibing specialized skill sets and professional attitudes. The students often face challenges in learning courses that demand higher levels of involvement and use extensive analytical approaches. Based on their earlier learning experience, the students need help developing a new thought process. Therefore, the role of the Instructor becomes vital to connect abstract concepts. Students need other allied topics if the course exists in collaboration. The teacher's responsibility begins too early in the process by helping students imbibe the practice of –learning how to learn. Teachers should gain deep insight into active learning techniques acquired through education-based conferences to train different learning styles. The systematic application of active learning helps entice students and develop critical thinking [11-12].

The course outcomes (COs) are statements defined by Course Instructors highlighting achievable targets through the teaching-learning process. These COs contribute to attaining Programme Outcomes developed to meet broad Graduate attributes. Typical course outcomes are listed below,

1. Demonstrate characterization of sensors: Ultrasonic sensor, IR sensor, Load cell, and Accelerometer.

2. Demonstrate the modeling of sensors and actuators.

Outcome-based education is effective when all stakeholders are actively involved in the process. The steps involved in the OBE framework include the following factors,

1. Institutional requirement: is defined by the vision and mission statement of the department. The Automation and Robotics Department follows the vision statement- to develop into a research-oriented department educating high-quality engineers to serve the diverse needs of our changing society. The Department's mission is to prepare undergraduate students with in-depth technical knowledge in mechanical, electronics, computers, control systems, and applications. The Automation and Robotics department has clearly articulated a vision for how problem and project-based pedagogies are integrated into its university objectives.

2. Program requirements: The program has a curriculum designed to draw inputs and feedback from Industrial and professional bodies. Program delivery stages include curriculum development, establishing program outcomes (POs), and mapping with the department's vision and mission. The structured curriculum emphasizes key learning through various levels of knowledge assimilation through understanding, analyzing, applying, evaluating, and creating. As part of the curriculum delivery, the student stakeholders will get a thorough insight into transforming theoretical concepts into practical utilities by applying acquired knowledge.

3. Course outcomes: Define relevant course outcomes focusing on higher coverage of POs with a well-defined framework to measure the attainment through appropriate Performance Indicators. The responsibility to set a threshold for assessment for subjects/courses comes under the purview of the course instructor.

4. Assessment: should reflect the knowledge and skills students acquire through the teaching-learning process for a specified course. Adopting a 'metric of assessment' clarifies this process and ensures transparency with a suitable mechanism to provide helpful feedback to students. The assessment tool, called the 'Assessment rubric,' incorporates measures that make it effective, valid, reliable, and fair. A well-designed evaluation strategy supports students'

learning opportunities and continuously tracks progress. The explicitly displayed, transparent, and continuous grading criteria make students identify good practices or lacunas in /their study pattern. The continually graded marking gives students ample scope to take corrective measures in case of any cavities found in the learning process. During the assessment, the stage-wise reviews include one-to-one interaction (viva) with each team member to ensure clarity in execution and progress monitoring. Participating members record each session in terms of deliverables and grades attained.

Design and description of the hardware:

The Measurement System laboratory course adopted a model-based design method to conduct the defined experiments. This approach analyzes system response when subjected to unexpected events or operating conditions. As part of these exercises, students will learn how to set up and receive data from various sensors like ultrasonic, accelerometer, infrared motion sensor, and a load cell sensor set up in this laboratory. Students learn using sensors by exploring calibration, range, and sensitivity features. The sensor feedback signals are non-linear and subject to situational changes induced by environmental parameters necessitating calibration. Figure 3 shows how the sensors and actuators interact with the real world. The themes in this laboratory may be used in problem-based projects. Most notably, the sensors serve as triggering mechanisms for initiating actions in response to a system built and acquiring knowledge on the sensor. The student gets insight into working principles, theoretical procedures, and application building using system identification for specific needs. The activity includes creating circuit diagrams, programming, characterization, and recording data. The exercise helps the student develop teaching hardware reinforced into the measurement system core course taught in an earlier semester [13-14].

The measurement laboratory adopts the Arduino Uno board to capture the range threshold with an interrupt instead of checking the range at every step. It does not take CPU execution until the threshold triggers. This hardware is interfaced with a personal computer or laptop via the MATLAB data acquisition module.

The laboratory course was incorporated through well-defined experiments provided at the beginning

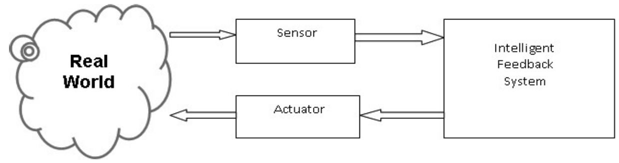


Fig. 3 : Sensor and Actuator interactions with the real world.

of the semester. The activity also included team formation in batches of 5 students each to facilitate peer learning between students. Peer learning promotes a catalyzing effect where students learn from each other and work collaboratively to solve specific real-world challenges enabled by applying problem-solving skills. Group activity helped students better visualize, document, and collaborate to yield better results [15-18].

A. Simulation

Simulation creates real-world situations or a model of some authentic phenomenon. The simulation technique is apt for application to the Measurement laboratory, owing to reduced traditional risk and easier replication of actual experiment circuits or hardware. It gives clear insights into complex problems to mimic system behavior. MATLAB simulator is a more powerful tool to analyze issues at different levels. The study uses MATLAB tools and Arduino IDE for simulation and data acquisition.

B. End Semester Assessment

The students' evaluation was done individually using the defined rubrics to assess Model design and documentation competencies. The assessment included a Viva session, closer scrutiny of output results presented by the teams, and student course feedback after the end-semester assessment. The elaborate questionnaire was prepared to capture the impact of the proposed exercise in the Measurement Laboratory regarding student interpretations of working principles of components, instruments, and simulation skills. The acquired benefits of this novel practice were assessed through the defined indicators that showed substantial benefits accrued in favor of students in terms of clarity in working principles of components, instruments, and simulation skills.

Upon completing the measurement system, laboratory student learning must evidence the defined COs in alignment with POs. The details of mapped POs for this course are presented in Table 1 concerning four defined course outcomes listed,

1. Demonstrate the principles of sensor characterization using sensor modules, namely, an ultrasonic sensor, an accelerometer, an infrared motion sensor, a Load cell sensor, and a variety of others.

2. Learn how to set up and interface with several basic sensors, including an ultrasonic sensor, an accelerometer, an infrared motion sensor, a load cell sensor, and a variety of others.

3. Learn how to calibrate, measure, and analyze data from those sensors.

4. Develop creative applications for the sensors.

Table 1: CO-PO Mapping- Measurement System Lab

PO→ CO↓	1.3	4.1	5.1	5.2	9.1
1	3				
2		3			
3				2	
4	3		2		2

L1 - Knowledge, L2 - Understand, and L3 - Apply represent the knowledge level as per Bloom's taxonomy. These course outcomes COs are mapped with the program outcomes (POs). A specific department's program outcomes (POs) must be aligned with twelve graduate attributes (GAs).

The course ensures students acquire new knowledge, complex problem-solving, communication, and higher-order thinking skills. This exercise also enables the course instructor to achieve program outcomes 1, 4, 5, and 9, as listed below.

Program Outcomes are:

1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to solve complex engineering problems.

2. Conduct investigations of complex problems: Use research-based knowledge and research methods, including design of experiments, analysis, interpretation of data, and synthesis of the information to provide valid conclusions.

3. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modeling, to complex engineering activities to understand the limitations.

4. Individual and Team work: Function effectively as an individual, member, or leader in diverse teams and multidisciplinary settings.

The significant advantages of lab courses lie in providing a platform to implement active learning methodologies and target the attainment of substantial POs defined for engineering programs. The changing technological scenario aims to develop innovative solutions to meet new challenges. This makes it essential for educational reforms to provide equitable space and opportunity for students to explore the engineering domain through new technological tools and methods. Experimentation forms an integral part of the academic domain that instills a thought process to think beyond the box and invent new techniques and strategies. The developments reported in engineering education literature strongly point towards using other methods to meet the needs of the current Industry. Engineering education faces new challenges to meet the emerging trends of making industry-ready graduates who can fit into corporate and academic research careers. PBL enhances the effectiveness of this lab course delivery [19-20].

4. Results & Discussion

The Lab course in the Measurement system is essential from the Industrial perspective. It is vital for emerging Industry-4.0 and Automation and constitutes a necessary segment in the Automation and Robotics Program. The identified course introduces the essential elements of measurement needed for any robotic or automation system. The measure is integral to any control system in identifying deviation in the intended system variable and its current value. The control systems handle various signals, including temperature, fluid flow, pressure, electrical resistance, noise level, the concentration of chemical species like pollutants, humidity, and illumination levels. Modern workspaces are expected to be more complex owing to unscrewed operations that pose challenging tasks to Automation engineers. Hence, a significant shift in technological thought processes will be witnessed to evolve disruptive technologies that will drive the future industrial sector. Given all these changes, it becomes imperative for top-notch universities to shift from their conventional curriculum to an advanced curriculum, befitting the disruptive technologies highlighted by Industrial mega-trends.

The need of the hour is to evolve an application-oriented curriculum that fits well with the changing industrial sector to educate our graduates anticipating the likely technology in the next decade or beyond. Graduating engineers will likely face obsolescence if these changes are not adopted within a few years of engineering practice. The course introduces students to designing simple tasks like evaluating the distance of objects from the target point, receiving voice signals, gauging the object's width through non-contact means, and similar automation-related jobs involving measurements. The reported work emphasizes imparting higher-order learning traits that make them self-driven learners and problem solvers. Engineering education should give flexibility to different types of learning communities. The modern learning community finds technological advancement changes. Project-based learning is the one to create clarity for the learning community.

Project-based learning has proved helpful to the students as it has made it possible to explore a creativity-driven approach to problem-solving through real-time problem statements. The PBL system adopts a more transparent and clearly defined assessment tool that ensures proactive learning and a higher degree of student participation. The assessment mechanism had periodic checks and feedback that dynamically induced students' confidence to proceed with the task at hand. PBL engaged the students to a greater extent, substantially improving attentiveness, attendance, positive learning attitude, complex problem-solving skills, higher-order thinking skills, communication skills, and improving students' academic performance.

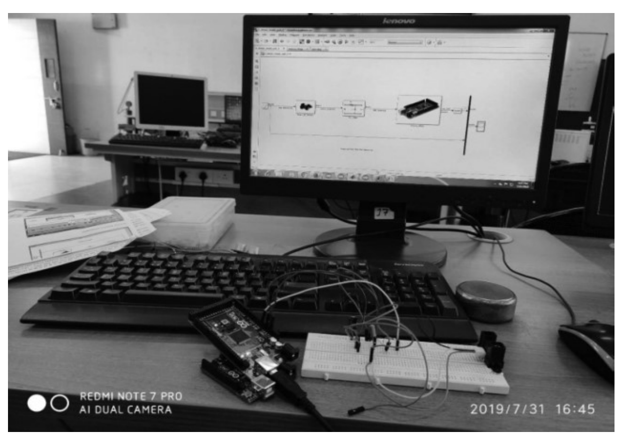
Through the PBL approach, students have gained knowledge on how to set up the experiment and receive data from various sensors, such as an ultrasonic sensor, an accelerometer, an infrared motion sensor, an ultraviolet sensor, and a load cell sensor used in the measurement system laboratory, and also learned simulation-based activities using MATLAB software. The students have learned to use various sensors by exploring the principles and specifications, such as calibration, range, sensitivity, etc.

Each experiment was assigned as project work for the group of students. Three or four students form a group or team. Hence, students learn how to work and communicate together, which helps to reflect on the project activities. The department facilitates the materials or components required to execute the experiment or project work. The course instructor or teacher encourages the students to work collaboratively to get accurate output.

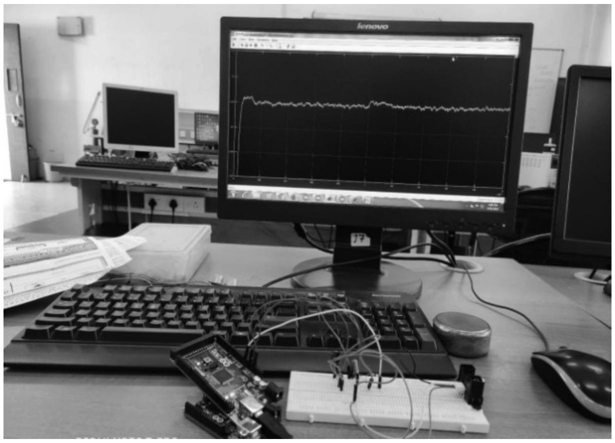
Figure 4 shows the conduction and execution of the experiment or project work in real time. Figure 4(a) depicts the group of students performing model-based design simulation,(b) describes the model-based design simulation output, c) represents the simulation showing the execution of the exercise, and (d) depicts the practically validating the practice.

Figure 4 explains the implementation of the PBL approach and how students are involved in the execution of experiments or project work. This clearly shows the students' engagement during the project and helps them acquire broad knowledge about the course.

a) Student group executing model-based design



b) Display of Model-based design simulation



c) Model-based Simulation output execution

d) Practical validation of Model-based study

Fig. 4: Simulation and validation of the laboratory exercises.

The end-semester assessment results of students presented in Table 2 and Figure 5 show considerable improvement in students' grades. The student performance was noticed over two consecutive batches of students who studied the lab course in the measurement system. The academic performance showed that the proposed PBL approach transformed students' outlook for the period. The whole perspective of teaching-learning changed, as indicated by the educational end-semester assessment of students trained through PBL, who performed better than those trained in Measurement systems to conventional lab delivery approach. However, initial challenges were to be handled during the implementation of the new initiative. The pioneers in engineering education enunciate that any change must be gradually brought in. Therefore, PBL was introduced to this course with good groundwork to avoid any panic situation for the stakeholders. The faculty or Instructors were given adequate time to master skill sets, understand the jargon of PBL, and implement it for the batch of students. The university provided all the facilities for successfully implementing PBL in this lab course. The sample data of the non-PBL cluster showed a comparatively lower performance level against the batch with PBL-based delivery.

With the implementation of PBL, the student's performance has improved compared to the preceding year when PBL was not implemented.

In addition to the end-semester assessment, student feedback is collected to qualitatively analyze the student's interest and approach to understanding the course. A course instructor has raised a set of questions to receive student feedback. The feedback questions are as follows.

- The project-led laboratory emphasizes the need to understand measurement systems in depth.
- Applying PBL in this laboratory course helped you dive deep into understanding the specifications of the measurement system.
- The laboratory course helped to improve complex problem-solving, higher-order thinking, and communication skills.

Figure 6 shows the analysis of student's feedback. The study revealed that the students have accepted implementing the PBL approach in the course. This positive response from the students helps an instructor implement the PBL approach to other courses in the future. The student's feedback analysis motivates the instructor to implement, and students learn through PBL.

Overall, the end-semester result analysis and student feedback analysis helped us qualitatively implement the PBL approach to the course. This is also a motive for implementing the PBL approach to the other courses.

Table 2: End Semester Assessment of Students.

Performance	Grade / Grade point	Marks in %	No of the students	Percentage
Outstanding	S /10	91 to 100	12	11.53
Excellent	A/ 9	81 to 90	32	42.30
Very Good	B/8	71 to 80	17	32.69
Good	C/7	61 to 70	8	11.53
Fair	D/6	51 to 60	0	0
Satisfactory	E/5	40 to 50	0	0
Fail	F/0	0 to 39	0	0

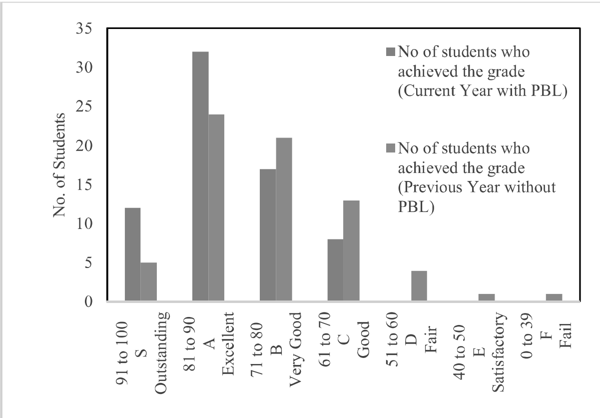


Fig. 5 : Comparative End semester Assessment results.

Implementing the PBL approach, the workgroup of 3 to 4 students has been formed randomly to work productively with different people. We had a whole 17 to 18 groups. The total number of workgroups is high, making it easy for the course teacher or instructor to conduct an expert review team has been formed to monitor and ensure productivity. One senior faculty member has been included in the expert review team to mentor the workgroups

The improved performance of the students in the course shows the importance of the PBL approach and its effectiveness. The analysis indicates that implementing the PBL approach in the courses helps develop the student's skills, higher-order thinking skills, and communication skills.

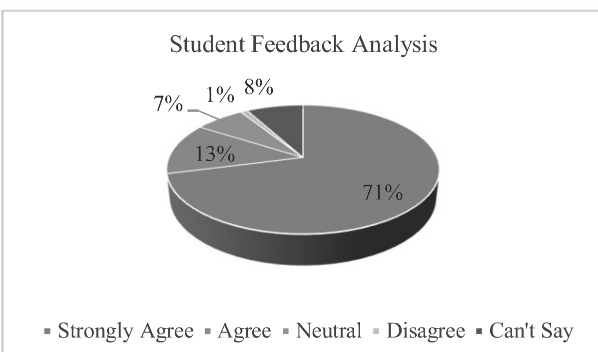


Fig. 6 : Student feedback analysis.

5. Limitations And Recommendations For Future Research

Regarding the PBL approach, work groups comprise 5 to 8 students in the sciences, while having just 3 or 4 in the engineering area is recommended. Once each teaching module is finished, groups are randomly reconfigured so students learn to work productively with different people. With such a small group, the total number of teams becomes enormously high, making it difficult for the course instructor to focus on ensuring productivity. In this investigation, we had a total of 15 groups.

The teacher takes on the role of facilitator or tutor, challenging the students to question their thinking and to find the best approach to understanding and resolving the problem. As the course progresses, the students can take on this role themselves and make the exact demands of each other. This requires a good peer learning ecosystem, which could be more decisive in our current scenario.

Generating appropriate problems lies at the core of learning and developing organizational skills. Hence, to create relevant issues, the course instructor needs to have strong support and mentoring from the competent faculty among the senior group.

The current research may be extended by considering principles, calibration, measurement, and analysis of the measurement system laboratory course to compare students taught through PBL and those who are not.

6. Implications

The improvements based on the PBL approach in the Measurement system Lab course positively impacted the teaching-learning process. The students received the changes well, creating a more exciting learning space. The implications of the study are presented,

· The faculty was challenged to develop modeling and simulation skills, new pedagogical techniques, approaches to assessment, and student management.

· Students were able to develop creative applications for the sensors.

· The laboratory course activities helped students build teams and collaboratively acquire problem-solving, higher-order thinking, and communication skills.

7. Conclusion

The measurement system laboratory course was introduced to undergraduate third-year automation and robotics department students. The experiments or exercises were conducted and implemented based on the PBL approach.

Implementing the PBL approach in the course comprised mainly of thinking creatively and acquiring new knowledge, which is hidden due to the previous year's conventional methodology. The project contains various activities, and PBL helped students work progressively. The PBL approach allows the students to focus on the project and motivates them to approach different skills.

The end-semester result analysis indicated the progress in achieving improved performance. The student feedback also evidenced their acceptance of the PBL approach. The end-semester result analysis and student feedback motivated the instructor to implement the PBL approach in other courses.

Implementing the PBL approach in this laboratory course also emphasizes self-directed learning. Finally, these considerations conclude that PBL may be the preferred way to engage students in the laboratory to fulfill the curriculum needs.

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