Original Article

IJEEE

International Journal of Electrical Engineering & Education
0(0) 1–15

DOI: 10.1177/0020720920928460
journals.sagepub.com/home/ije
SAGE

Fundamentals of Automation Engineering: A hybrid project-based learning approach

Devika Kataria[1], Gustavo Sanchez[1] and Siddhartan Govindasamy[2]

Abstract

This paper describes authors' experience with designing and teaching a new course on "Fundamentals of Automation Engineering", based on a hybrid Project-Based Learning approach. The proposed challenge for students was to develop a low-cost Material Handling Machine, equipped with basic control functions. The project was executed in three stages, with different activities/tasks performed during each stage, which finally led to successful completion of the challenge. Detailed course file containing syllabus, learning objectives, assessment rubric, project goals, and deliverables was provided to students at first stage. Handouts and assignments were also provided weekly to students, which required extensive use of library resources (self-learning). Feedback survey was conducted fortnightly and suggestions were considered for course improvement. In this paper, authors discuss course organization, learning and assessment activities, and perception of students.

Keywords

Hybrid project-based learning, electrical engineering education, automation

[1]Institute of Engineering and Technology, JK Lakshmipat University, Jaipur, India
[2]Franklin W. Olin College of Engineering, Needham, MA, USA

Corresponding author:
Devika Kataria, JK Lakshmipat University, Ajmer Road, Near Mahindra SEZ, Jaipur 302026, India.
Email: devikakataria@jklu.edu.in

Introduction

Institutions of higher education are constantly under pressure to improve the quality of their service, to attract and retain better students and professors, to get more research grants, etc.[1] Different types of pedagogy have been explored so as to imbibe continuous learning in students, making them future ready professionals as well as embedding entrepreneurship. Project-Based Learning (PBL) has been reported to help students in developing self-learning and problem-solving skills.[2] Early exposure to engineering practice through this approach can promote a deeper development of professional skills (team work, open-ended real-life problem-solving, etc.), overcoming other issues like boredom during class and lack of content relevance.[3]

Many authors have reported PBL experiences related to Electrical and Electronics Engineering, namely:

1. O'Mahony (2008) presented an experience in translating a traditional course to an integrated dual-impact course that utilizes a collaborative project to drive the learning. This author states that most groups succeeded in designing a PI(D)-based controller for their system: an inverted pendulum or ball-and-beam system.[4]
2. Lei et al. (2012) proposed to build a Rube Goldberg machine: a comically involved invention, laboriously contrived to perform a simple operation.[5] The students were allowed to use daily life objects as well as components like switches, relays, sensors, actuators, mechanical parts, etc.
3. Cocota et al. (2015) discussed the design and development of a low-cost robot manipulator with six degrees of freedom.[6] Students carried out activities during two years, analyzing issues like forces involved, kinematic models, trajectory planning, control strategies, and performance assessment. A similar project was proposed in López-Nicolás et al.[7]
4. Fernandes (2015) described a project-based learning laboratory for teaching embedded systems. The goal was to design and implement a temperature control system for an industrial drier, equipped with a remote interface for configuration and data acquisition.[8]
5. Zapata et al. (2015)[9] proposed an aerial robotic system as a toolkit, together with learning activities focused on automation and robotics like: system identification, pattern tracking, navigation, etc. This toolkit involved two parts: the quad-rotor (Parrot AR Drone) and the ground station control.
6. Song and Dow (2016) proposed to develop an autonomous car able to engage in a Sumo-like competition to see which car remains the longest within the border of a given arena.[3]
7. Iturregi et al. (2017) proposed to design an electrical installation, given technical, economical, and legislative specifications.[10] Their project spanned from second year up to final college year.

Despite all these important experiences, basic theoretical concepts (usually taught in first or second year courses) are still considered to be difficult to integrate with PBL. In fact, some authors even claim PBL approach is costly and ineffective because it requires more resources to obtain similar outcomes. Studies on the effectiveness of PBL have mixed conclusions, but in general show good results in longer-term knowledge retention.[11]

However, ineffective PBL can affect whether students acquire sufficient domain knowledge.[12] Thus, some authors recommend to follow *hybrid* instructional frameworks that promote self-directed learning and problem-solving skills, without sacrificing knowledge of fundamental theoretical principles.[13,14]

Another important current trend in engineering education is the rising demand for qualified automation engineers, as more companies look for efficiency, cost savings, and sustainability of their businesses.[15] In this domain, besides control system modeling, analysis, and design, it is necessary to learn about many other aspects like maintenance requirements, industrial communication networks, performance of control strategy, execution constraints, interdisciplinary teamwork, among others.[16] Therefore, it is not surprising that automation and control systems are widely viewed to be one of the hardest courses to understand in engineering education.[17]

This paper describes authors' experience designing and teaching a new course on "Fundamentals of Automation Engineering", following a hybrid PBL approach as an option to cope with the challenges presented above. The rest of the paper is organized as follows: in section "Course organization", the course organization is described; course structure, learning outcomes, and content framework are discussed. Section "Learning and assessment activities" presents learning and assessment activities. Finally, in sections "Perception of students" and "Conclusions", student's feedback and concluding remarks are presented.

Course organization

The course *Fundamentals of Automation Engineering* (FoA) is aimed at building key technical competencies needed by automation engineers. It is focused on promoting basic knowledge and critical understanding of different technologies involved in the design and maintenance of automated systems. It is a first year 6 credit core course for all engineering undergraduate branches, with 6 h of studio sessions and 2 h of tutorials per week. The course is led by an interdisciplinary team of faculty which includes electrical, electronics, and automation engineers. On successful completion of this course, students should be able to:

a. Evaluate the benefits and challenges of different automation technologies.
b. Develop a complete solution for a simple automation problem (including: power supply, actuator, sensor, data acquisition, and control) given a set of engineering constraints: accuracy, energy, cost, environment, etc.
c. Explain the importance of adopting suitable engineering standards and good management practices for automation projects.

The course is divided into the Units showed in Table 1. Note that the planned duration of each Unit was three weeks, although the actual duration was slightly different because topics like System Dynamics required more time than expected to be properly understood.

Learning and assessment activities

Diverse learning and assessment activities were designed for students. Theoretical concepts were addressed in classical lectures and tutorials. The project execution was divided into four stages which ultimately lead to the common goal of developing a Material Handling Machine: e.g. conveyor belt, elevator, crane, etc. equipped with basic control functions, sensors, and display (see Figure 1). The motivation behind this project is a trade-off between relevance, availability of components in the local market, complexity, and cost.

In next sub-sections, each project stage will be described in detail. Note that in terms of theoretical concepts, each stage can be mapped to one Unit in Table 1.

Stage 1: Linear power supply

During this stage, students were involved in design and implementation of a DC linear power supply. Project goals and their weight were defined by instructors based on expected learning outcomes, as shown in Figure 2, based on the conceptual framework proposed in Stolk and Martello.[18] The slider bars are used to emphasize the connection between goals and course's activities, deliverables, and assessments.

Handouts were provided to students a week in advance to help them with self-directed learning. The concepts explained included basic circuit analysis, transformers, semiconductor PN junctions, filter design, and ripple factor measurement. Tutorials were conducted for students twice a week on numerical problems to develop their analytical skills. The class of 54 students was divided into 13 groups. Each group was assigned the project statement including the specifications of the DC power supply.

One of the three different voltage ranges (5, 9, or 12 V) power supplies were to be designed by each group. Self-directed learning was inculcated to help them study and discuss the handouts on rectifier circuit, filter circuit design, and identify the need of regulator in the supply.

Real world applications of transformers, DC supplies, and regulation of voltage were discussed. Hands-on skills on making printed circuit boards (PCBs), soldering of electronic components, and measurements using digital storage oscilloscopes were imparted to the students. A sample power supply fabricated by one of the groups is shown in Figure 3. At the end of this stage, students submitted a detailed analysis of the power supply performance.

Table 1. Course units: Learning outcomes and theoretical content.

Unit	Unit learning outcomes	Theoretical content
Introduction to Electrical Engineering—three weeks	• Analyze and design basic electrical circuits • Measure power consumption and circuit parameters • Design and build a Printed Circuit Board • Build and test a linear power supply, given specifications • Follow basic electrical safety practices according to standards	• Basic electric circuit analysis • Power calculations • Phasors. Single phase and three-phase wiring • Transformers • Linear Power Supply • Electrical safety
Introduction to Automation Engineering and Control Systems—three weeks	• Formulate mathematical models for basic electro-mechanical systems • Design and implement a basic analog open-loop control system (including power supply, switches, LEDs, DC motor, etc.) • Conduct a basic analysis of control system performance and identify the need for feedback	• Introduction to Automation and Control Systems: open and closed loops • Block diagrams • Introduction to System Dynamics. Developing linear models • Modeling and simulation of an electro-mechanical system
Introduction to Digital Circuits—three weeks	• Evaluate and simplify logic functions • Implement and test basic combinational and sequential circuits with minimum complexity • Implement logic functions through software, using micro-controller	• Boolean Algebra • Karnaugh maps • Logic gates, decoders, and multiplexers • Displays • Flip-flops, counters and timers
Introduction to Instrumentation and Embedded Systems—three weeks	• Explain basic concepts related to measurement and instrumentation according to standards • Identify the key features of embedded systems in terms of hardware and software • Develop simple programs for embedded devices • Design and test a simple embedded system to collect and process real-time data	• Measurement concepts • Working principle of sensors: motion detection, gyro motors, vision, sonar, laser, tactile • Architecture (concepts on ALU, memory, ports) • Applications on sensors interfacing with microcontroller

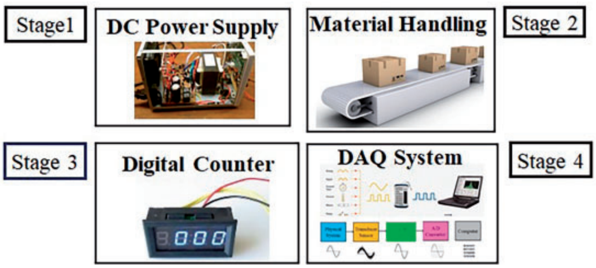

Figure 1. Proposed project: four stages.

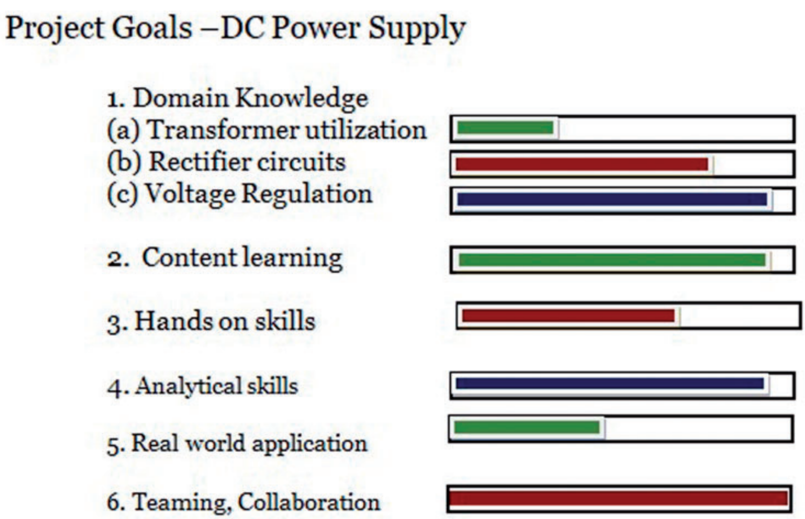

Figure 2. Identification of goals for Stage 1: DC power supply.

Stage 2: Mechanical building and basic control system

The second stage of the project dealt with building a Material Handling Machine. First, at an introductory level, the concepts of automation life cycle and architectural levels and layers (automation pyramid[19]) were discussed according to Reference Architecture Model Industrie 4.0 (DIN SPEC 91345). Specific examples of sensors and actuators, field level industrial controllers (PLCs), and Supervisory Control and Data Acquisition Systems (SCADA) were illustrated.

Students deliberated upon applications where automation could significantly enhance productivity and efficiency of processes. Material Handling systems were discussed and the role of automation to help logistics in industry was explored. The students were familiarized with project charters and each team prepared a project charter where they identified the processes involved in mechanical

Figure 3. Example of DC power supply made by a group of students, where bridge rectifier is made using IN 4007 diodes, capacitors, and inductor of specific rating are used to remove ripples in voltage and current, and voltage regulator IC is used for supply voltage regulation.

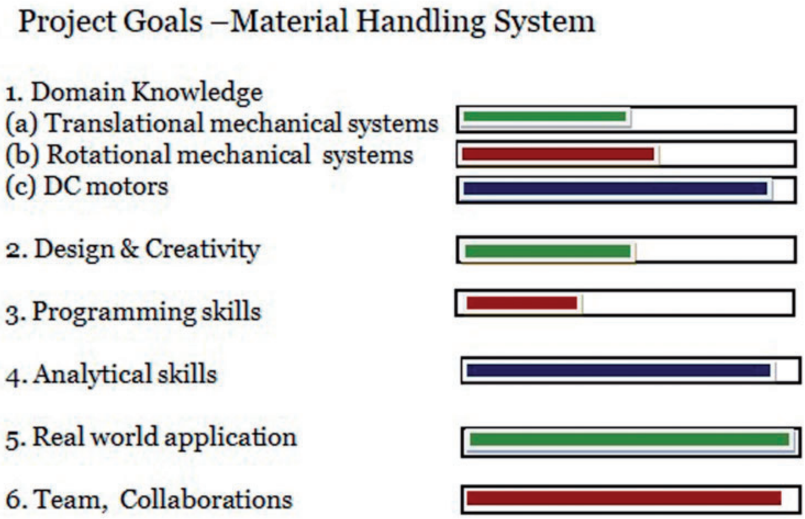

Figure 4. Identification of Goals for Stage 2: Material Handling System.

building of their material handling system, made dimensional drawings, listed the bill of materials, and mentioned the deliverables. The lead faculty identified the goals for this stage as shown in Figure 4. Analytical skills, linking with real-world application and collaborative work, were given high weightage in this stage.

The next two weeks were engaged in delivering fundamental concepts of control systems. Significance of dynamic modeling of mechanical systems was appreciated

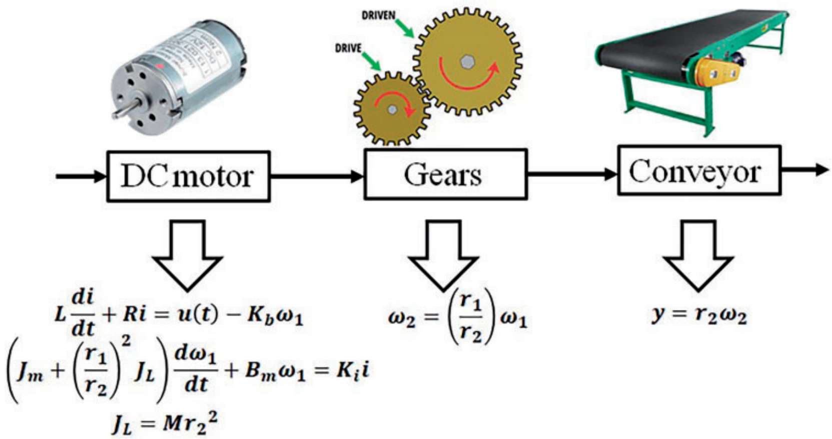

Figure 5. Block diagram for Material Handling Machine.

by the students and equations governing the dynamics of DC motors, gears, and other mechanical parts were explained as shown in Figure 5. The students were provided lectures and tutorials to help them master the differential equations, to make them adept at writing equations for dynamic systems.

Simulations were done to calculate the torque provided by the DC motor and calculate the maximum load that could be carried by the system, taking into effect the losses due to friction. The theoretical calculations were compared with actual physical measurements on the systems. The teams submitted a detailed report on the analysis done by them.

It was observed that the students worked with great enthusiasm and with team spirit during this stage. The team members identified their roles—each member had some role like design, fabrication, testing, and report writing. The teams made group presentations and individual viva voce was held for each student. Quizzes were conducted on the concepts taught and mentoring was done for students who required help in analytical skills.

Stage 3: Digital counter design

This stage involved the design of a digital circuit. The concepts learned by students included combinational circuits, logic functions, minterms, maxterms, etc. An activity on the design of a combinational circuit for seven-segment display was carried out, were the concepts learned on Karnaugh Maps of minimization of literals were used and the minimized logic was implemented using logic gates.

The concept of synchronous and asynchronous digital circuits was discussed and the requirement for clock generation for synchronous circuits was identified. Discussions on sequential circuits, state diagrams, and timing diagrams for

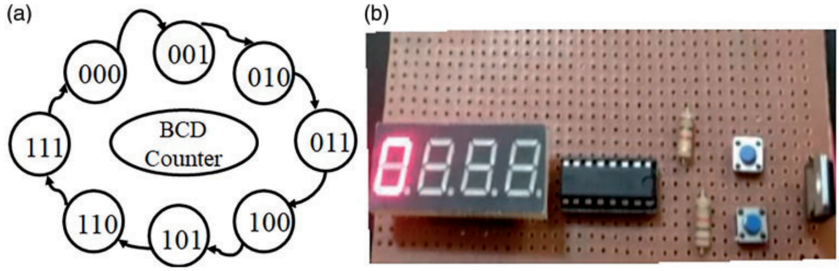

Figure 6. Digital counter. (a) State transition diagram for decade counter and (b) counter IC CD4026 interfaced with seven-segment display and using pushbutton switches for counting and reset.

counters were done in class. A mini-project on counter interfacing with seven-segment display was undertaken by students, see Figure 6.

Stage 4: Data acquisition system

The final stage for project was aimed to interface temperature sensor LM 35 with the Arduino ATMEGA 328 P microcontroller system. The project goals identification for this project are shown in Figure 7.

The architecture of Arduino Nano boards having 14 digital I/O pins, 8 Analog I/O pins, flash memory of 32 KB with 2 KB of boot program, and clock speed of 16 MHz were discussed as an available system for the project. Handouts were provided for Arduino standard library functions and instructions for installation of Arduino Integrated development environment was provided to the students.[20] Advantages of digital data acquisition systems were deliberated upon, namely ease in design, and information storage, implementation of logics by programming, immunity of digital signals to noise, and maintenance of accuracy and precision in measurements. The fundamental blocks of embedded system comprising of sensor units, control/processor unit, and actuators/display were introduced. Serial communication protocol using Universal Asynchronous Receiver Transmitter (UART) was explained to students and communication at specified baud rate between Arduino Nano board and laptop serial port was demonstrated to the class, as a first step toward building a basic sensor network IoT application.

Tutorials were held where the students were made to interface switches and LEDs to digital pins, interface potentiometer to analog pin to display the voltage of variable knob, interface seven segment display to Arduino, and read a string of data from hyper/tera terminal of a laptop. The activities and tutorials were conducted for three weeks and necessary concepts were developed for students for this stage of the project. The block diagram of the data acquisition system, as shown in Figure 8(a) was discussed in the class and the students were provided datasheet of the precision centigrade temperature sensor LM 35. The linearity scale of

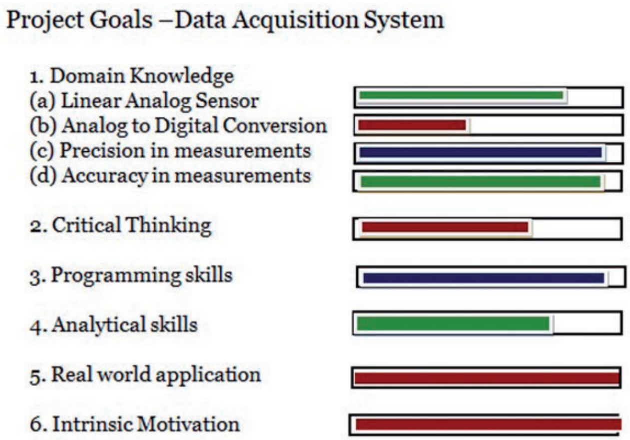

Figure 7. Identification of goals for project Digital Temperature Measurement.

10-mV/°C Scale Factor was highlighted for calculations in the project.[21] The goal of the project was to imbibe critical thinking amongst the students to enable them to understand and use the datasheet.

Programming skills developed during tutorial exercises were deployed to interface the temperature sensor with the microcontroller board. Intrinsic motivation was found to be high in this stage of project and students had shown keen interest during the tutorials for programming. The students made measurements and analyzed their results. They used a calibrated thermometer to measure the temperature of the heat sink of power supply regulator, and this reading was taken as standard temperature. The readings obtained from the sensor were analyzed by plotting frequency of measurements vs temperature as shown in Figure 8(b). Precision and accuracy were estimated on these graphs and critique report was published by each team.

The following assessment activities have been planned. Note that classical theoretic assessment through Mid-Term and End-Term examinations still has 40% of weight in the final grade, whereas project carried 30% weight, which therefore justifies our hybrid PBL approach. The fundamental engineering principles are assessed using the Rubric shown in Figure 9 which shows that continuous assessment of student's performance was done through assignments and periodic quizzes.

Perception of students

Feedback was taken from students periodically during the course, so as to take corrective actions when needed. In this paper, we present the results of two anonymous surveys (Mid-Term and End-Term) of overall course student perception, in a Likert scale where 1 is most negative and 5 is most positive. The proposed

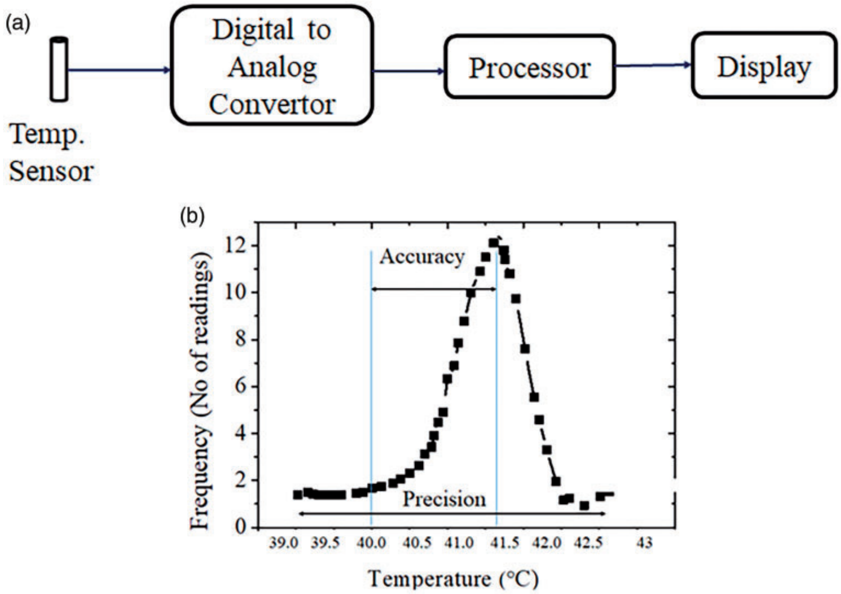

Figure 8. (a) Data acquisition system for reading temperature of power supply heat sink at periodic sampling intervals. (b) Temperature graph shows measurement of accuracy with calibrated thermometer being taken as standard value and precision of measurement showing.

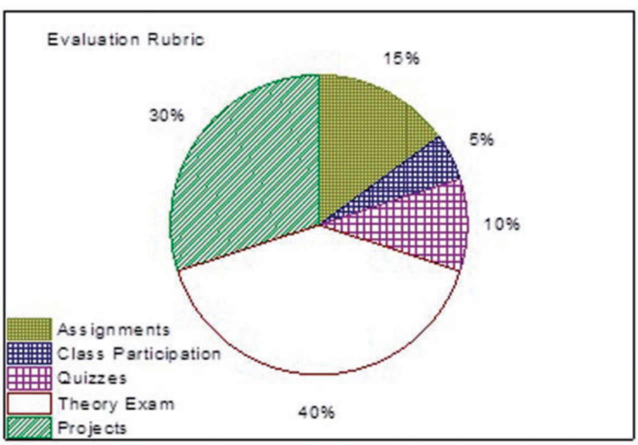

Figure 9. Evaluation rubric for the course showing continuous evaluation by assignments, quizzes, theory exams, and project presentations.

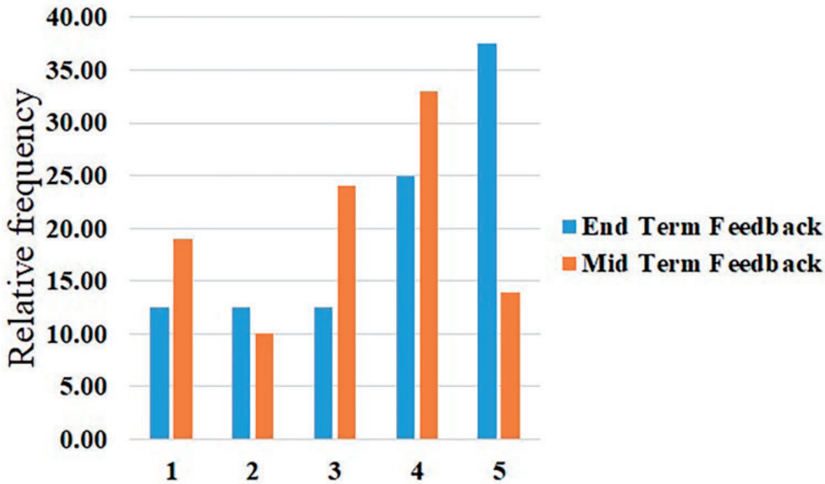

Figure 10. Student's overall course perception: 1 is most negative and 5 is most positive.

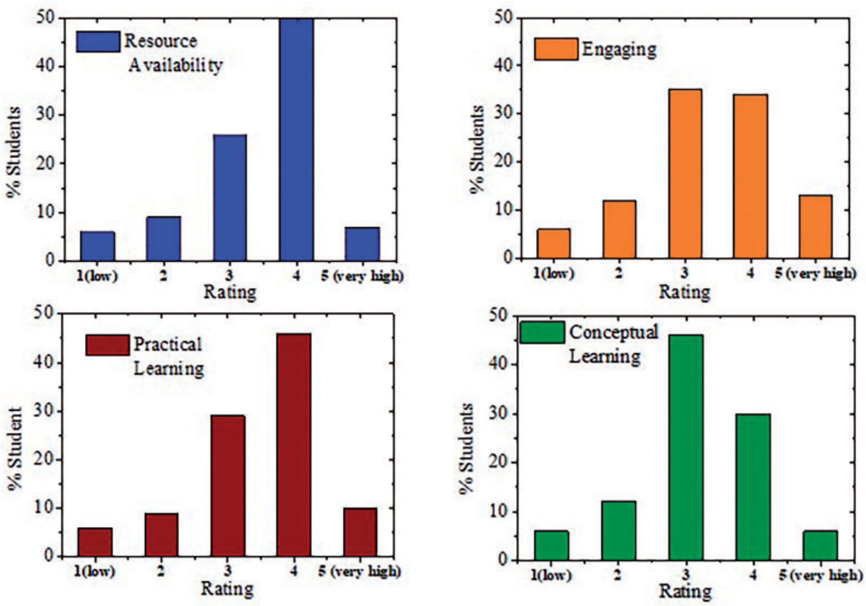

Figure 11. Feedback survey results for specific parameters taken at the end of course.

question was: *How will you rate the course overall?* Positive and very positive perception increased from 45% (Mid-Term) to 60% (End-Term).

In the feedback in Figure 10, 99% students suggested that the project was highly relevant to real world of automation engineering. The feedback also revealed that the concepts learned during discussions helped them in practice and analysis of project. Student's perception on specific aspects of course delivery obtained through end of course anonymous survey is shown in Figure 11. The results of this survey show that the learning through practical implementation was high, and conceptual learning was good. The survey also reveals that nearly 15% of students suggested that all the four aspects could be improved, and deliberations within instructors suggest this could be addressed by making resources more accessible (with due care for human safety), increasing the classroom participation and introducing more interesting and challenging activities.

The challenges seen by students were soldering of IC bases as this required precision work using a microtip soldering iron. Students also found the mechanical modeling of dynamic control systems to be difficult; however, when they were provided enough tutorials and practice through white board interactions, quizzes, and tutorials, they were confident of writing the differential equations for dynamic systems. The reports written by students were impressive and showed that the analytical skills were instantiated.

Conclusions

The course received a high rating in the feedback, the students were observed to take good interest in learning concepts and applying them in the project. The level of student engagement in all the activities was high and it was found that though the projects were done in collaborative manner, the learning by individual students could be assessed and feedback provided when necessary. Students developed hands-on skill in fabrication, connecting electrical motors, transmission of power through transformers and mechanical gear systems, and understood the relevance of automation and IoT technologies for their careers as future engineers. They developed good communication skills as they made presentations at each stage of the project. The report writing helped students to develop good analytical and academic writing skills.

Acknowledgements

The authors acknowledge the management at JK Lakshmipat University for their motivation and support for the new pedagogy which has been implemented for 2018–2022 batch of undergraduate students at the university. The support by colleagues and laboratory staff at Electrical and Electronics Engineering, JK Lakshmipat University is highly appreciated and valued.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Devika Kataria https://orcid.org/0000-0002-8071-8922

References

1. Berman EP and Paradeise C. Introduction: the university under pressure. In: *The university under pressure*. Research in Sociology of Organization, Bingley, UK: Emerald Publishing, 2016,vol 46, pp.1–22.
2. Govindasamy S, Christianson RJ, Geddes J, et al. A contextualized, experiential learning approach to quantitative engineering analysis. In: *2018 IEEE frontiers in education conference (FIE)*, San Jose, CA, USA, 2018, pp.1–5. Piscataway, NJ: IEEE.
3. Song J and Dow D. Project-based learning for electrical engineering lower-level courses. In: *American Society for Engineering Education 123rd annual conference and proceedings*, New Orleans, Louisiana, June 26-29 2016, p.25978.
4. O'Mahony T. Project-based learning in control engineering. In: *IET Irish signals and systems conference (ISSC 2008)*, Galway, Ireland, 2008, pp.72–77. London, UK: IET.
5. Lei C-U, Kwok-Hay So H, Lam EY, et al., Teaching introductory electrical engineering: project-based learning experience. In: *Proceedings of IEEE international conference on teaching, assessment, and learning for engineering (TALE) 2012*, Hong Kong, China, 2012, pp.H1B-1–H1B-5. Piscataway, NJ: IEEE.
6. Cocota JAN, D'Angelo T and de Barros Monteiro PM. A project-based learning experience in the teaching of robotics. *IEEE R. Iberoamericana Tecnologias Aprendizaje* 2015; 10: 302–309.
7. López-Nicolás G, Romeo A and Guerrero JJ. Project based learning of robot control and programming, In: *International Conference on Engineering Education and Research*, Korea, 2009. p.6.
8. Fernandes MAC. Project-based learning laboratory for teaching embedded systems. *Math Prob Eng* 2015; 2015: 1–8.
9. Zapata García DF, Garzón Oviedo MA, Pereira Valente JR, Barrientos A. QuadLab: a Project-Based Learning Toolkit for Automation and Robotics Engineering Education. *J Intell Robot Syst*, 81: 91–116. DOI: 10.1007/s10846-015-0204-4.
10. Iturregi A, Mate E, Larruskain DM, et al. Work in progress: project-based learning for electrical engineering. In: *2017 IEEE Global Engineering Education Conference (EDUCON)*, Athens, Greece, 2017, pp.464–467. Piscataway, NJ: IEEE.
11. Yew EHJ and Goh K. Problem-based learning: an overview of its process and impact on learning. *Health Prof Educ* 2016; 2: 75–79.
12. Hung W. The 9-step problem design process for problem-based learning: application of the 3C3R model. *Educ Res Rev* 2009; 4: 118–141.

13. Han Y-L, Cook K, Shuman T, et al. Development of authentic engineering problems for problem-centered learning. In: *2016 ASEE annual conference & exposition proceedings*, New Orleans, Louisiana, 2016, p. 26821. DOI: 10.18260/p.26821.
14. Self B, Widmann J and Adam G. Increasing conceptual understanding and student motivation in undergraduate dynamics using inquiry-based learning activities. In: *2016 ASEE annual conference & exposition proceedings*, New Orleans, Louisiana, 2016, p.25668. DOI: 10.18260/p.25668.
15. Sullivan L. Want to become an automation engineer? Here's what it takes. *Lisa Sullivan's Blog*, April 2015, www.thearmadagroup.com/blog/lisa-sullivan (2002, accessed 10 May 2020).
16. Fernández-Samacá L, Ramírez JM and Orozco-Gutiérrez ML. Project-based learning approach for control system courses. *Sba Controle & Automação* 2012; 23: 94–107.
17. Jayaram S. Implementation of active cooperative learning and problem-based learning in an undergraduate control systems course. In: *Presented at the 120 American Society for Engineering Education annual conference*, Atlanta, 23-26 June 2013.
18. Stolk JD and Martello R. Reimagining and empowering the design of projects: a project-based learning goals framework. In: *2018 IEEE Frontiers in Education Conference (FIE)*, San Jose, CA, USA, 2018, pp.1–9. DOI: 10.1109/FIE.2018.8658981.
19. Sauter T. Integration aspects in automation – a technology survey. In: *2005 IEEE conference on emerging technologies and factory automation*, Catania, Italy, 2005, vol. 2, pp.255–263. DOI: 10.1109/ETFA.2005.1612688.
20. www.arduino.cc/en/Tutorial/Foundations (accessed 10 May 2020).
21. Data sheet for LM35 Precision Centigrade Temperature Sensors, http://www.ti.com/lit/ds/symlink/lm35.pdf (accessed 10 May 2020).