Improving Program Outcome Attainments Using Project Based Learning approach for: UG Course - Mechatronics

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Abstract: In the era of rapidly emerging technical society, engineering aspirants must be primed as globally competent. To respond, in recent years, inclusive reforms are being implemented to adopt Outcome-Based Education (OBE) approach and transform engineering education in India. The 12 Program Outcomes (POs) defined by NBA guides for development, execution & delivery of curriculum, evaluation of student learning and performance at various levels. The scope of mechatronics subject at colleges affiliated to Savitribai Phule Pune University (SPPU) in 2015 course was mostly restricted to theoretical and study approach, which do not exhibit involvement of students in creative, inventive and innovative thinking. This motivates to adopt Project Based Learning (PBL) at undergraduate level. Three large classes of 70+ students are grouped in to 3-5 students per batch. Project phases are defined; direct and indirect assessments are mapped with outcomes and it is carried out using pre-and post-intervention survey of students. It is observed that, the presented PBL framework has served as an efficient pedagogy. This approach not only ensured holistic development, teamwork, sustainability, improved higher-order cognitive skills, learning ability, soft skills, self-efficacy and communication but also accumulated near about 60 innovative prototypes in a mechatronics laboratory. It is projected that, PBL could enable students to acquire lifelong learning to tackle new difficulties arise in corporate/non-corporate life, thinking on future modification, filing a patent, converting prototype into commercial product.

Keywords: Program Outcomes, Project-Based Learning, Mechatronics.

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1. Introduction:

The engineering students must be prepared to be globally competent in view of rapid growing technical community. To respond, in recent years, inclusive reforms are being implemented to adopt Outcome-Based Education (OBE) approach and transform engineering education in India. OBE helps to execute higher-order learning and professional skills which are essential for Graduate Trainee Engineer (GTE) in the industry [1-2]. The 12 Program Outcomes (POs) defined by NBA guides for development, execution & delivery of curriculum, evaluation of student learning and performance at various levels. [3].

Specifically, a base aptitude is to be nurtured to engineering students and is achieved by strategic procedure, methodical analysis and testing of design solutions preceding execution. It is this body of knowledge – the practical, technical discipline of complex problem solving – that is most germane to a student’s post-university working life. The ability to solve problems systematically, without guidance, is broadly applicable to engineering in many contexts in mechatronics and beyond [4].

In that context, a Project-Based Learning is considered to be the best platform for the students to attain noteworthy profundity of comprehension of ideas, more extensive information base, improved correspondence and relational/social aptitudes, upgraded authority abilities, expanded innovativeness, and improved composition abilities [5]. This paper advocates the use of PBL as a key pedagogical method for teaching a Mechatronics course in curricula of Third year-Mechanical Engineering (TE-ME), Savitribai Phule Pune University, Pune. The scope of mechatronics subject of TE-ME (2015 course) at colleges affiliated to SPPU was mostly restricted to theoretical and study approach, which do not exhibit involvement of students in creative, inventive and innovative thinking [6]. To bridge the gap in teaching-learning process for the said course, PBL approach is recommended. Recently, as per 2019 pattern of First Year Bachelor of Engineering Choice Based Credit System, course named 'Project Based Learning (110013)' is included for all first year engineering branches.

In first semester of academic year 2018-19, a different approach for teaching Mechatronics subject was employed, in which innovative design tasks were presented within the scheme – that is, the essence of the pedagogical approach in theory period and laboratory work – of project based learning. The students were introduced to the project based learning approach by educating them in development of problem to reach to the solution. The students are expected to undertake both the team-work gaining-by-dealing with dynamic, along with implication of the technical procedures and self-coordinated learning of problem based learning. The problems assigned are inferior to project layout itself, permitting students to adopt flexible methodology to achieve the objective in accordance with highest skill level and level of attainment. Hence PBL helps students to attain most of POs at high level [7-9].

This paper describes the framework of PBL for Mechatronics course, particularly, which is offered at third year mechanical engineering programme of SPPU. The effectiveness of use of PBL methodology to attain course outcomes (COs) and programme outcomes (POs) is presented here. Section1 introduces need and applicability of PBL as an effective pedagogy for Mechatronics course. Section 2 briefs about general design of PBL scheme. The construction of class and evaluation is given in section 3. In the 4th section, a case study incorporating the PBL scheme is elaborated to showcase the evidence of success. The 5th section includes detailed results and discussion. A conclusion is stated at the end of the paper.

2. Design of PBL scheme

The multi-dimensional features of PBL scheme include target-driven, adaptable, multi-resolutioner, gradual attainment, self-contained to tolerate failure etc. As far as the mechatronic domain is concern, it initiated with the goal of implementing multi-resolutions and reflected as self-explanatory due to target-derived approach. Adaptability of the scheme implies a venture where the objectives and methodology for achieving aim might be effectively altered or acclimated to comply with emerging aptitude levels or class targets. Multi-resolutioner describes how to organize the objective to allow a few (or unbounded) parallel arrangements that might be disparate from a desired or determined solution. Self-contained to tolerate failure explicitly gratifies the structure of mechatronic control system design and interface strategy, where minor mistakes may lead to can generous forfeit [10-11].

Three large classes of 70+ students are grouped in to 3-5 students per batch. Project phases are defined as; Identification of problem statement, literature review to find out research gap, Methodology proposal, Mechanical design, Electronic system design, Theoretical approach/numerical analysis, Software simulations, Mechatronic Integration, Prototype demonstration, delivery, service and repairs. In this PBL approach students are motivated to serve as a practical, productive in the learning, progressing in the direction of fulfilling one or more problem statements. The project tilted 'Development of Arduino based compact size pesticide spraying drone', 'Arduino based 3D Wire Bending Machine', 'Arduino based Robot Arm with Smartphone Control', 'Arduino based Robot Car with Wireless Control', Arduino based RFID Door Lock', 'IoT Based Patient Monitoring System using ESP8266' and 'Arduino Interface of MEMS sensors and Arduino for developing data loggers for temperature, acceleration, noise, power consumption, fluid flow' etc. were allotted to various groups as given in Annexure II.

The scheme proposed in this paper, differs from the classic theme as in implementing the PBL not only by demonstrating the prototypes but also with intention of holistic development of students and corresponding deliverables to the society. Within the context of a project/problem-based framework, specific well-scoped challenges were introduced to assess students based on additional aspects such as Budget, Quality of report, Communication, confidence, Application in terms of real time implementation, Publications, Appreciations if any for inspiring students to locate their degree of accomplishment.

3. Construction of class and Evaluation

Construction of class and evaluation are considered as the direct indicators and reflects how effectively PBL based system plan is executed. The problem statement of the project sets an end point for the students; many students might be relied upon prioritising marks over the educational objectives. Evaluation, consequently, ought to interlace, one to prove that PBL offers high quality and the procedure of appraisal is itself influential. In PBL based system configuration, class (where group cooperation and synergistic improvement techniques are to be focused) this fundamentally requires stability between the team work and individual evaluation.

The evaluation comprises of specialized technical reporting procedures to assess and analyse project growth (for example weekly reviews, presentations and report notes), which intent to furnish the student with a progressively certified instructive experience (that is, to be proportionate with expert designing practice) and acclimate them with modern procedures, both in on paper and verbal medium. The evaluation is incorporated to correlate objectives and efforts with the deliverables using pre-and post-intervention survey of students. The COs and POs for mapping to evaluation are as follows:

The COs of Mechatronics defined by SPPU is [6]:
At the end of course, graduate student will be able to:

1. Identify of key elements of mechatronics system and its representation in terms of block diagram
2. Use the concept of signal processing and interfacing systems such as ADC, DAC, digital I/O
3. Analyze interfacing of Sensors, Actuators using appropriate DAQ micro-controller
4. Analyze system model in Time and Frequency domain (for control application)
5. Install PID control on real time systems
6. Develop prototype for real life application

The POs defined by NBA are [3]:
At the end of program, graduate student will be able to:

1. Engineering Knowledge
2. Problem Analysis
3. Design/development of solutions
4. Conduct investigations of complex Problems
5. Modern tool usage
6. The engineer and society
7. Environment and sustainability
8. Ethics
9. Individual and team work
10. Communication
11. Project management and finance
12. Life-long learning

3.1 Direct Assessment

The direct assessment of the projects is carried our using aspects and respective evaluation scheme as stated in table 1. The rules were designed considering the CO of mechatronic course stated by SPPU and PO by NBA. The industry and academic expert team was designated for direct assessment of the projects. The students were asked to prepare PPT presentation for conducting the assessment along with the prototype demonstration. The performance evaluation is done using the scale of 100. The below expectation project were rated to < 40%. The projects meeting to the expectations were rated from 40% to 75%. The projects above expectations were rated > 75%. The performance indicators are stated in Annexure I.

Table 1: Rubric used for direct assessment

S.N.	**Assessment aspects**	**CO**	**PO**
1	Feasibility of methodology	6	7
2	Mechanical design	1,3	3
3	Electronic system design	1,3	3
4	Theoretical /numerical analysis	2,4	2
5	Use of software/simulations	2,4	5
6	Selection of various components	1,3	1
7	Mechatronic Integration	2,3,4,5	1
8	Prototype demonstration	6	3
9	Aesthetic and ergonomics considerations	6	3
10	Experimentation, testing and calibration, validation	6	3
11	Interpreting the results, conclusion	6	3
12	Budget	NA	11
13	Quality of report	NA	11
14	Communication, confidence	NA	10
15	Application in terms of real time implementation	6	7
16	Publications, appreciations	NA	6

3.2 Indirect Assessment

The indirect assessment is carried out by students survey post the PBL activity. The students were asked to rate themselves for self-assessment to check the satisfaction level and to attain the POs. The survey is carried out by using the aspects stated in table 2. The linkage of various aspects with the COs and POs is presented in the same table. This is helped in attaining the outcomes at course and program level. The performance evaluation is done using the scale of 100. The rating below 40% indicates 'strongly disagree', 40 to 75% indicates 'somewhat agree' and above 75% indicates 'strongly agree'.

Table 2: Rules used for indirect assessment

S. N.	**Aspects**	**CO**	**PO**
This activity enriched my technical abilities by:			
1	Reviewing the existing scenario to identify functional gap	1	1,4
2	Fulfilling defined problem statement	1	1
3	Fulfilling pre-defined objectives	1	1,4
4	Identifying the need of problem statement	1	6
5	Identifying the methodology	1,2	2,3
6	Analyzing the problem using software/simulations	2,4	5
7	Identifying various components required for developing prototype of mini project	1	2,3
8	Applying use of sensors, actuators	1	1
9	Reviewing the construction and working of sensors, actuators	1	1
10	Selecting various components w.r.t to required specifications	1	1
11	Developing interface of hardware and software	3,5,6	1
12	Developing the prototype	3,5,6	3
13	Performing the testing and calibration of prototype, validation	3,5,6	3
14	Interpreting the results, finding conclusion and learning from failures if any	3,5,6	3
15	Identifying and applying aesthetic and ergonomics considerations	1	6,7

This activity enriched my project-management abilities by:			
1	Leading the team, inspiring others, setting the vision	NA	9
2	Negotiating the people and resolving conflicts by finding the win-win scenarios	NA	9
3	Employing scheduling, time planning for delivering desirables more successfully	NA	11
4	Formulating and implementing of resource planning	NA	11
5	Learning the finance, budgeting, costing, auditing	NA	11
6	Executing risk management	NA	11
7	Identifying pros and cons of solutions to problems and hence critical thinking	NA	11
8	Improving communication, confidence, willpower	NA	10
9	Learning quality management	NA	11
10	Identifying the real-world application & open-ended nature of the project motivated me	NA	6,7,12
This activity enriched curricular vitae/profile by:			
1	Applying thought process of converting a prototype into commercial product	NA	6,7
2	Participating in competition	NA	6
3	Filling of a patent	NA	6
4	Publishing journal papers	NA	6
5	Presenting work in conferences, workshops	NA	6
6	Organizing training programs	NA	6
7	Starting the consultancy	NA	6

4. Case study

The list of projects allotted to number of groups is given in Annexure II. The link of this assignment was shared to the students on webpage. One of the project as case study is discussed here. The project titled ‘Development of low cost vibration monitoring system using open source hardware and software [12-15].

- *Title:* Development of low cost vibration monitoring system using open source hardware and software
- *Need:* Vibration analysis is important aspect in machine condition monitoring and is used for predicting and quantifying a significant change in process parameters which leads to failure.
- *International/national status:* Many types of vibration analysers are available for health monitoring of a machine but the overall cost is very high and may not be affordable to all.
- *Motivation:* In an era of low cost instrumentation it necessitates to develop a low cost system which will fulfil the entire requirement.
- *Problem statement:* To develop a vibration monitoring system which is easy to handle, low cost and has good accuracy during its life cycle.
- *Objective:* To display time and frequency domain graph to analyse trend of frequency.
- *Methodology:* To identify requirement of system in terms of specifications, identify sensor, microcontroller, find suitable software, design and simulate program, develop system, test, calibrate, conclude.
- *Selection:* A low cost microcontroller Arduino Mega 2560 is used here along with accelerometer ADXL335 and is integrated with MS-Excel to store & display the acquired data.

- *Mechatronic integration and prototyping :*

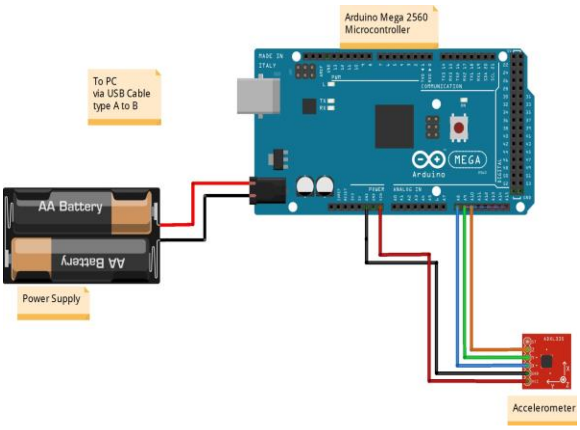

Figure 1: Mechatronic integration

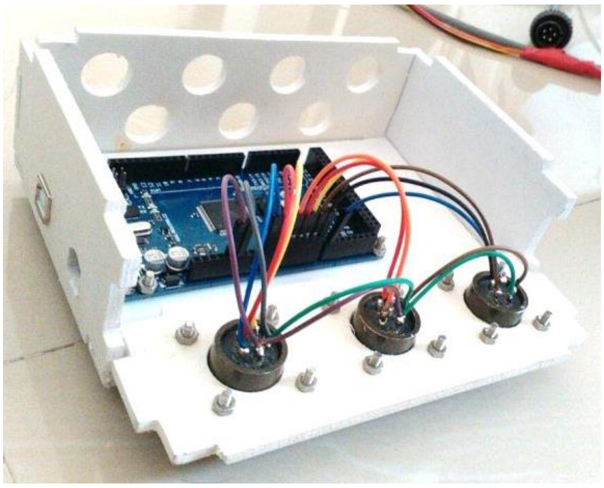

Figure 2: Prototype with three channels for accelerometer

- *Programming:* The programming to acquire data in MS-Excel, two software were used such as Arduino IDE and PLX-DAQ. The conversion of time domain response to frequency domain is carried out in Excel using FFT command in data analysis tool.

- Experimentation, validation: The system was experimentally tested on a cam jump apparatus at various speeds. The results (time domain and frequency domain responses) were recorded for each reading. The system is calibrated with existing system and was found to have an accuracy of 98.93%.
- Publication/appreciation: This group of 4 students attended and presented paper in national conference named 'National Conference on Research and Development in Mechanical, Electronics and Civil Engg (NCRDMECE-2018)' held at Pune in February 2018.

5. Result and discussion

The direct and indirect assessment is carried out using rules stated in section 3 for all the project groups (total 60). The result of direct assessment is shown in table 3.

Table 3: Result of direct assessment

SN	Assessment aspects	Expectation scale (No of groups out of 60)		
		(< 40%)	(40- 75%)	(> 75%)
1	International and national status of the project	5	40	15
2	Need of the problem statement	12	37	11
3	Feasibility of methodology	8	44	8
4	Mechanical design	4	48	8
5	Electronic system design	2	40	18
6	Theoretical approach/ numerical analysis	10	42	8
7	Use of software /simulations	2	45	13
8	Selection of various components	0	45	15
9	Mechatronic Integration	2	48	10
10	Prototype demonstration	10	40	10
11	Aesthetic and ergonomics considerations	25	29	6
12	Experimentation, testing and calibration, validation	18	32	10
13	Interpreting the results, conclusion	20	32	8
14	Budget	2	50	8
15	Quality of report	30	20	10
16	Communication, confidence	15	35	10
17	Application in terms of real time implementation	14	30	16
18	Publications, appreciations	30	25	5

The result of indirect assessment is shown in table 4:

Table 4: Result of indirect assessment

SN	Aspects	Satisfaction scale (No of groups out of 60)		
		(< 40%)	(40- 75%)	(> 75%)
This activity enriched my technical abilities by:				
1	Reviewing the existing scenario to identify functional gap	2	42	16
2	Fulfilling defined problem statement	12	33	15
3	Fulfilling pre-defined objectives	10	35	15
4	Identifying the need of problem statement	15	32	13
5	Identifying the methodology	6	45	9
6	Analyzing the problem using software/simulations	0	46	14
7	Identifying various components required for developing prototype of mini project	0	44	16
8	Applying use of sensors, actuators	2	40	18
9	Reviewing the construction and working of sensors, actuators	4	39	17
10	Selecting various components w.r.t to required specifications	5	40	15
11	Developing interface of hardware and software	5	35	20
12	Developing the prototype	10	35	15
13	Performing the testing and calibration of prototype, validation	15	33	12
14	Interpreting the results, finding conclusion and learning from failures	18	34	8
15	Identifying and applying aesthetic and ergonomics considerations	28	24	8
This activity enriched my project-management abilities by:				
1	Leading the team, inspiring others, setting the vision	5	15	40

2	Negotiating the people and resolving conflicts by finding the win-win scenarios	10	24	26
3	Employing scheduling, time planning for delivering desirables more successfully	15	30	15
4	Formulating and implementing of resource planning	10	28	22
5	Learning the finance, budgeting, costing, auditing	1	25	27
6	Executing risk management	6	32	22
7	Identifying pros and cons of solutions to problems and hence critical thinking	12	38	10
8	Improving communication, confidence, willpower	20	35	5
9	Learning quality management	8	36	16
10	Identifying the real-world application & open-ended nature of the project motivated me	16	30	14
This activity enriched curricular vitae/profile by:				
1	Applying thought process of converting a prototype into commercial product	12	32	16
2	Participating in competition	35	20	5
3	Filling of a patent	40	12	8
4	Publishing journal papers	30	24	6
5	Presenting work in conferences, workshops	25	25	10
6	Organizing training programs	50	8	2
7	Starting the consultancy	39	15	6

The overview on the results inferred that both the mechatronic theory course and the PBL approach assisted students to enhance their aptitudes in regards of mechatronic domain. The results are self-explanatory and self-evident. It confers that specific objective of the course is being satisfies for most of the aspirants. The PBL is served as an proficient framework as it not only ensured holistic development, teamwork, collaboration, sustainability, improved higher-order cognitive skills, learning ability, soft skills, self-efficacy and communication but also accumulated near about 60 innovative prototypes in a mechatronics laboratory. What's more, PBL could enable students to acquire lifelong learning to tackle new difficulties arise in corporate/non-corporate life, thinking on future modification, filing a patent, converting prototype into commercial product.

5. Conclusions

This paper described the framework of PBL for Mechatronics course, particularly, which is offered at third year mechanical engineering programme of SPPU. The outline of the general PBL frameworks design is presented. Also the construction of class and evaluation which influence the project-problem scheme is elaborated. A case study incorporating this scheme is elaborated in detail as a evidence of success. The report of PBL outcomes using direct and indirect approach is presented. In the era of low cost instrumentation, this approach has become realistic due to the advances in MEMS technology, open source hardware and software etc. The cheering response from the students demonstrates that the application of PBL is a effective pedagogy to make our students ready to be globally competent. The students' involvement is raised to such level that they are thinking on future modification, filing a patent, converting prototype into commercial product etc.

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Annexure I

Performance indicators for assessment:

Sr. No.	Assessment aspects	No. of groups		
		Below expectations (below 40%)	**At expectations (40-75%)**	**Above expectations (above 75%)**
1	International and national status of the project	No literature review exists/No comparison with existing systems. No research gap exists.	Some of the aspects compared with existing systems. The solution may address the research gap for some of the aspects.	The problem has been recognized, researched, solved previously by other approaches. There exists research gap. The current problem addresses the research gap.
2	Need of the problem statement	Poor SWOC analysis	Average SWOC analysis	Perfect SWOC analysis
3	Feasibility of methodology	The methodology is doubtful to address the objective.	The methodology is certainly to address the objective.	The methodology is greatly to address the objective.
4	Mechanical design	Poor use of mechanical design principles	Partial use of mechanical design principles	Exact use of mechanical design principles
5	Electronic system design	Poor use of electronic design principles	Partial use of electronic design principles	Exact use of electronic design principles
6	Theoretical approach/numerical analysis	No execution of Theoretical approach/numerical analysis	Limited execution of Theoretical approach/numerical analysis	Proper execution of Theoretical approach/numerical analysis
7	Use of software/simulations	Fails to use software/ No simulations	Software programming partially executes the required output/ Simulations are average.	Correct designs of algorithms and implementation using software/ presented simulations
8	Selection of various components	Incorrect selection of components	Some of the components were selected as per requirement	Perfect selection of components as per required specifications/design
9	Mechatronic Integration	Fails to integrate various parts	Partially integrates the various parts	Accurately integrates the various parts
10	Prototype demonstration	No prototype developed	Limited working of the prototype	Prototype satisfies the defined objective
11	Aesthetic and ergonomics considerations	Aesthetic and ergonomics considerations were not considered	Some aesthetic and ergonomics considerations were employed	Professional consideration of Aesthetic and ergonomics aspects
12	Experimentation, testing and calibration, validation	Poor experimentation ability/ No calibration/ No validation	Carried experimentation but failed to calibrate and validate	Experimented, tested, calibrated and validated the model accurately
13	Interpreting the results, conclusion	Wrong results/ No conclusion	Partial results are correct but not reliable Limited conclusion	Correctly interpret the results and conclusion meets the objective
14	Budget	Poor	Average	Perfect
15	Quality of report	No report/Poorest quality	Satisfactory	Professional
16	Communication, confidence	Lack of Communication, confidence	Somewhat likely to communicate with average confidence	Sound communication with full of confidence
17	Application in terms of real time implementation	Fail to implement in real time application	Likely to implement in real time application	Perfect for implementation in real time application
18	Publications, appreciations	Fail to publish, present it to others	Neutral about presentations and publications	Presented and published in conference/journal Participated in competition