Implementation of Problem Based Learning in Mechatronics System Design course

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***Abstract*—This paper presents the implementation and evaluation of Problem Based Learning (PBL) in a Mechatronics System Design (MSD) course aimed at 3rd year undergraduate engineering students. Integrating PBL into the course curriculum seeks to enhance student's understanding of complex mechatronic systems and their ability to design innovative solutions. The implementation process involved the identification of authentic, real-world problems relevant to mechatronics engineering. The System composer module of MATLAB tool is used to build virtual prototype, integrate, and test the problem. This module helps to follow the V model or VDI2206 guidelines. Throughout the course, students engaged in active problem-solving activities, conducting research, analyzing data, and applying theoretical concepts to develop practical solutions. Faculty members serve as facilitators, guiding students through the problem-solving process while encouraging self-directed learning and collaboration among peers. Assessment methods evaluate the student's technical competence and ability to work effectively in teams, communicate ideas, and use modern tools. Preliminary results indicate that implementing PBL in the Mechatronics System Design course has led to positive outcomes in student learning and engagement. Surveys and student feedback reveal increased motivation, confidence, and satisfaction with the learning experience. Furthermore, students demonstrate improved problem-solving skills, a deeper understanding of mechatronic principles, and enhanced abilities to collaborate in interdisciplinary teams.**

***Keywords*— MATLAB System composer, V model or VDI2206 guidelines, Virtual prototyping**

***JEET Category*—Practice**

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I. INTRODUCTION

Up until now, Mechatronics System Design course has followed a traditional theoretical/lecture-based format, where teachers deliver lectures, students take notes, and exams determine their success in the subject. However, this approach often results in students forgetting the material over time, posing challenges when designing automation systems in the future. To address this issue, transitioning to a practice/project-based format focused on real-time problems can significantly reduce the likelihood of skill deterioration. By engaging students in hands-on projects and practical applications, they are more likely to retain the skills learned in the course and apply them effectively in real-world scenarios.

The V-Model is a systems engineering process that emphasizes the verification and validation of the system at each stage of development. It consists of two main streams: the left side of the V represents system definition and decomposition, and the right side represents integration and verification, as shown in Fig 1. Each step on the left side of the V corresponds to a validation step on the right side, ensuring that the requirements and specifications are met at each level[1].

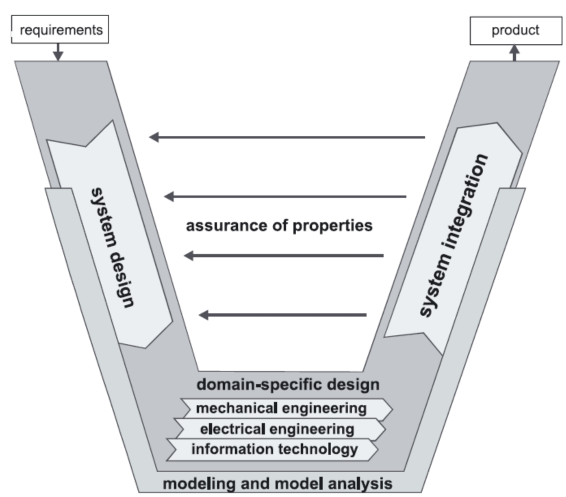

Fig. 1. V-model of the VDI 2206:2004 guideline "Design methodology for mechatronic systems" (VDI, 2004)

TABLE I
COURSE OUTCOMES, COURSE STRUCTURE /DELIVERY PLAN AND ASSESSMENT STRATEGY FOR MSD COURSE

Course Outcomes	Delivery Plan: Teaching & Learning activities	Assessment Methods
1. Explain significance of V-Development lifecycle model for Mechatronics system design.	Case study	Project Implementation plan
2. Analyze the problems and requirements of the system through customer interaction and Market surveys.	Case study in MATLAB Requirement tool box	Review of Requirements & Surveys
3. Formulate the specifications to achieve the functions.	MATLAB system composer case study	Review on Specifications
4. Design a system for requirements and specifications in a team.	Model based design in MATLAB system composer using Simulink, Simscape, Multibody	Conceptual designs Review
5. Apply component selection technique for components selection.	MATLAB Requirement tool box	Bill of Materials
6. Propose a prototype to address the solution in a team.	Model based design in MATLAB system composer using Simulink, Simscape Multibody	Final Project simulation Review
7. Evaluate the prototype for customer satisfaction.	MATLAB Model based design	Customer feedback

It is noticed that in many literature Problem Based Learning and Project Based Learning are used interchangeably. Both the PBLs are fairly similar in theory. Both are student-centered strategies that encourage the teacher to serve as the facilitator. Problem Based Learning is centered around solving a real life complex problem, with a primary emphasis on the process of reasoning, inquiry and solution finding. The focus is on the process of solving a real-world problem. While Project Based Learning emphasis the creation of a product, with a focus on applying knowledge and skills to produce something tangible. Many authors accepted PBL and implemented in Mechatronics theory & lab with few improvements[2][3][7][12]. PBL is used as pedagogy at multilevel in curriculum, spread across different semester in the form of workshops which are interconnected[4][11]. Web-based environment is used to deliver Mechatronics content as remote learning tool. Author outlines the architecture and limitations of approach[5]. Study shows an educational strategy for Mechatronics laboratories education which integrates the Tecnológico de Monterrey Educational Model, industrial technologies and equipment, hands-on activities, laboratory equipment based on Design for Mechatronics Learning (DFML) and an e-Learning platform to improve communication between teachers and students[6][14]. A study consolidates different new methods in applied Mechatronics and PBL is one among them adding multiple advantages[8][13]. Efforts are made in bringing in Product development into Mechatronics by applying PBL framework[9]. Mechatronics as Capstone design course is delivered in close context of industrial methodologies to prepare industry ready graduates[10].

II. IMPLEMENTATION PROCESS

As we embark on implementing the Problem-Based Learning approach for the first time, it's important to plan the delivery, design the course, monitor the execution of overall process and designing assessment.

A. Planning phase

The institute, recognizing the need for improvement in student learning experiences, embarked on a journey of innovation. Initially, faculty members lacked familiarity with problem-based learning , and there were no dedicated studios for course delivery. However, under the guidance of the institute leaders, the syllabus and framework underwent multiple reviews. To equip faculty with the necessary skills, comprehensive PBL training sessions were conducted.

After attending five workshops and numerous supervision meetings, we gained valuable insights into implementing Problem-Based Learning in our courses with the guidance of experts. Through self-reflection and extensive reading of relevant articles, we developed a deeper understanding of our subject knowledge and the principles of PBL. This process instilled confidence in our ability to constructively align course outcomes (COs), assessments, reflections, and activities. As a result, we feel prepared to transform our course into a PBL format.

Constructive alignment provides a comprehensive overview and effectively integrates all components of Problem-Based Learning, including course outcomes, teaching/learning methods, and assessment strategies. The Constructive alignment ensures that course planning, design, and implementation remain aligned with the procedures of Problem-Based Learning. Table.1 consolidates the Course outcomes, course structure/delivery plan and assessment strategy for MSD course in detail.

B. Design phase

Designing and structuring the PBL curriculum to align with the learning objectives while integrating VDI2206 standards, case studies, and MATLAB System Composer required significant time and effort. Ensuring access to necessary resources, including case studies, software licenses for MATLAB System Composer, and relevant instructional materials, posed challenges, especially in ensuring equitable access for all students. Transitioning from a traditional lecture-based teaching approach to a facilitative role in guiding student-centered learning activities required developing new facilitation skills and strategies. Managing group dynamics among students working collaboratively on PBL projects presented challenges, including addressing conflicts, ensuring equitable participation, and balancing individual contributions within groups. Developing appropriate assessment methods and criteria to evaluate student learning and performance in PBL projects, including assessing problem-solving skills, critical thinking abilities, and collaboration, required careful consideration and planning. Integrating MATLAB System Composer software tool for hands-on learning posed challenges related to technical support, training students on software usage, and troubleshooting technical issues during lab sessions. Balancing the time allocated for PBL activities, including problem-solving sessions, group discussions, and hands-on learning with MATLAB System Composer, within the course schedule proved challenging, especially considering other course requirements and constraints. Ensuring that students were adequately prepared for the self-directed and inquiry-based nature of PBL, including possessing the necessary prerequisite knowledge and skills, required providing additional support and scaffolding as needed. Continuously evaluating and refining the PBL implementation based on feedback from students, assessment data, and reflection on teaching practices required ongoing effort and commitment to improvement.

Third year undergraduate students of Mechanical department and Automation & Robotics department have Mechatronics System Design course for 4 credits. Each division consists of around 60students. Students have no prior experience of PBL pedagogy. But they have acquired all prerequisite technical knowledge during their earlier courses like Control system, Mechatronics, Engineering Exploration and Design courses. Student teams are formed, consisting of not more than 6 students in a team. Mechatronics System Design course is linked with Minor project. Students select a Problem statement as a part of Minor project. Same problem statement is considered in MSD and Virtual prototype is built using Matlab tool. Physical prototype is built as part of Minor project. Virtual prototyping follows V model. There will be 3 sessions of MSD (of 2 hrs each) every week. Usually, during 1st and 2nd session there will be delivery on V model and Matlab tool by taking simple examples/application. Students should practise these examples. And in 3rd session students should apply concepts to their selected problem to get solution.

C. Execution of course

Initially, when employing a PBL approach, students exhibited reluctance. However, their perspective shifted as they engaged in activities, eventually leading to appreciation for the approach. Over time, they came to realize the importance of problem-based learning.

The change in teaching practice involved shifting from traditional lectures to an interactive, problem-solving environment. Each session included specific activities that required students to apply theoretical knowledge to practical scenarios, promoting active learning and critical thinking. Data collected included students' project outcomes, feedback surveys, and performance assessments.

The system composer module of MATLAB tool is used to build, integrate, and test the problem. This module helps to follow the V model or VDI2206 guidelines. The course is delivered in studio mode, where students sit teamwise and work on the chosen problems. Students have explored multiple modules of MATLAB like Simulink, Simscape multibody, System composer, Requirement toolbox and Test harness toolbox. The Mechatronics System Design course model is presented in Fig 2. After freezing the need statement, the requirements are converted into engineering specifications and entered into MATLAB Requirement Toolbox. Overall system design & architecture is constructed using MATLAB System Composer. Each component of System Composer is then provided with component level modeling and analysis using MATLAB Simulink, Simscape and Multibody modules. System Integration is ensured by verification and validation of virtual prototype by using MATLAB Test Harness module. The overall process is iterative in nature and leads to product improvement.

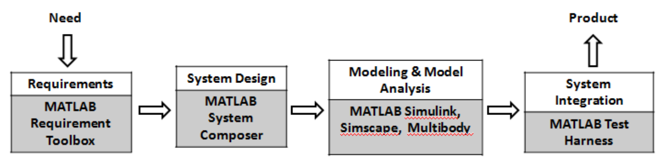

Fig. 2. Mechatronics System Design course delivery model

A supportive learning environment was cultivated to encourage students to take risks, ask questions, and seek assistance when needed. Instructors and facilitators were accessible to provide guidance, feedback, and support throughout the PBL process.

Throughout the course, students adhered to the VDI2206 methodology, which includes steps such as requirements collection, specification writing, system design, modelling and simulation, component design, prototyping, and testing. During the design process, students gathered extensive data from users and utilized various evaluation instruments such as designs, calculations, CAD models, architectures, simulations, prototypes, and algorithms. In addition to these instruments, students' problem-solving approaches, level of involvement in activities, and their ability to overcome challenges also served as valuable indicators for evaluating their progress and learning outcomes.

D. Teaching and Learning Activities

Problem-Based Learning Sessions:

Students engage in problem-solving activities where they work in groups to tackle real-world mechatronics system design challenges.

Activities include identifying the problem, conducting research, analysing data, brainstorming solutions, and presenting findings.
Role of the Teacher: Facilitates discussions, provides guidance, and offers support as students navigate the problem-solving process.
Learning Outcomes: Develops critical thinking, problem-solving, and collaboration skills while applying theoretical concepts to practical problems.

Case Studies/Examples Analysis:

Students analyse 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 Design methodology of VDI2206 framework.
The design of mobile robotic guidance system in the form of smart wheelchair is explained in detail here to address methodology. The first phase, which begins with the problem statement formed after interacting with wheelchair users, is followed by the analysis of user requirements, which are converted into system specifications. The second phase is design of concepts, components design with actuator and sensor selection, etc., and integration of sub-systems and the entire system, which also includes control system design, control algorithm selection, sensor placement, and integration. The complete virtual prototype process involves modeling, simulation, and analysis of the system, followed by physical prototyping. And finally, user inspection and review of the smart wheelchair.

Activities involve studying the design, functionality, and implementation of these systems, identifying key components, and understanding their applications.
Role of the Teacher: Guides students in exploring case studies, facilitates discussions on design principles and applications, and helps connect theoretical concepts to real-world examples.
Learning Outcomes: Enhances understanding of mechatronics system design principles, fosters the ability to analyse complex systems, and illustrates the practical relevance of theoretical knowledge.

Hands-On Activities with MATLAB System Composer:

Students engage in hands-on learning activities using MATLAB System Composer software tool.
Activities include simulating and designing Mechatronics systems, such as personal aerial vehicles and Autonomous mobile robots, within the MATLAB environment.
Students experiment with system parameters, analyse simulation results, and iterate designs based on performance feedback.
Role of the Teacher: Provides instruction on using MATLAB System Composer, guides students in setting up simulations, and facilitates discussions on simulation results.
Learning Outcomes: Develops proficiency in using simulation tools for mechatronics system design, reinforces theoretical concepts through practical application, and enhances problem-solving skills through iterative design processes.

Overall, these teaching and learning activities are designed to provide students with a holistic understanding of mechatronics system design principles and their practical applications. Through a combination of problem-solving, case study analysis, and hands-on experimentation, students develop critical thinking, collaboration, and technical skills essential for success in the field of mechatronics.

E. Assessment

Handling large class sizes can indeed pose challenges, particularly during the review process and thorough assessment. It may require careful planning and organization to ensure that each student receives adequate attention and feedback. Implementing strategies such as group work, peer review, and utilizing technology for assessment can help streamline the process and ensure effective learning outcomes for all students.

We analysed the project outcomes by evaluating the functionality, creativity, and technical accuracy of the mechatronics systems designed by the students. Feedback surveys provided insights into student's engagement, motivation, and perceived effectiveness of the PBL approach. Performance assessments measured improvements in problem-solving skills, understanding of mechatronics concepts, and proficiency with MATLAB System Composer.

The evidence collected showed a significant increase in student engagement and a deeper understanding of mechatronics systems. Projects demonstrated high levels of innovation and practical application of VDI2206 principles. Survey results indicated that students felt more connected to real-world problems and appreciated the hands-on learning experience. Overall, the implementation of PBL pedagogy using VDI2206 methodology and MATLAB System Composer proved to be an effective strategy for enhancing the Mechatronics System Design course.

Here's a breakdown of the assessment types, timing, instruments used, and learning outcomes assessed:

Formative Assessments:
Timing: Throughout the learning process, occurring at regular intervals.
Instruments: In-class quizzes, peer assessments, group discussions, and self-assessments.
Learning Outcomes: Assess students' understanding of theoretical concepts, problem-solving skills, collaboration, and critical thinking abilities as they engage with case studies, MATLAB System Composer software tool, and other learning sources.

Summative Assessments:
Timing: Towards the end of each project or learning module.
Instruments: Project reports, presentations, demonstrations, and assessments of final designs or prototypes.
Learning Outcomes: Evaluate students' overall mastery of mechatronics system design concepts, their ability to apply

knowledge to real-world problems, and their capacity to communicate and justify design decisions. Assessments also gauge students' proficiency in using MATLAB System Composer and their understanding of VDI2206 standards.

Performance Assessments:
Timing: During hands-on activities and practical exercises.
Instruments: Performance rubrics, observation checklists, and feedback from instructors and peers during lab sessions and demonstrations.
Learning Outcomes: Assess students' practical skills in implementing designs, troubleshooting, and optimizing mechatronics systems using MATLAB System Composer. Evaluate their ability to work effectively in teams, follow safety protocols, and adhere to VDI2206 standards.

Each student is assessed for 100 marks. In semester assessment(ISA) carries 80% weightage whereas End semester assessment(ESA) carries 20% weightage. Table 2 gives detailed assessment framework, criteria and breakdown of marks.

Overall, these assessment strategies aim to provide a comprehensive evaluation of students' learning experiences and outcomes in mechatronics system design, including both theoretical knowledge and practical skills acquired through problem-based learning activities and hands-on exercises using MATLAB System Composer.

TABLE 2
ASSESSMENT FRAMEWORK, CRITERIA AND BREAKDOWN OF MARKS

	Assessment	Marks
	ISA Assessment	
1.	MATLAB Simulink course Certification	5*
2.	Analysis of the requirements i.e., customer needs & Literature Review	5
3.	Developing the specifications of the system to achieve the functions	10
4.	Design of the system with concepts and proper numerical	5*+10
5.	Selections of components for the system with proper calculations	5*+10
6.	Proposing the prototype to address the solution	5*+15
7.	Validation & Feedback	5*+5
	ISA total	80 marks
	ESA Assessment	
1.	Individual Learning	6*
2.	Project Report	6
3.	Project presentation	8*
	ESA total	20 marks

Note: * Assessment is on individual contribution

III. Results

The implementation of Problem-Based Learning pedagogy in the Mechatronics System Design course, utilizing the VDI2206 methodology, has yielded significant outcomes. The integration of real-world case studies involving unmanned aerial vehicles, cobots, and autonomous mobile robots has enhanced students' engagement and practical understanding. Using MATLAB System Composer as a tool for simulation and architecture design has further solidified their technical skills. Students have demonstrated improved problem-solving abilities and a deeper grasp of mechatronics system design principles through hands-on activities in each session. The shift from traditional lectures to PBL has fostered greater collaboration and critical thinking among students, as they work on projects that mirror real-world challenges.

One of the key outcomes is the successful completion of comprehensive mechatronics systems as final projects, showcasing the students' ability to apply theoretical knowledge to practical applications. These projects have not only met academic requirements but have also demonstrated innovation and creativity in design. The anticipated results include a higher level of student satisfaction and confidence in tackling complex engineering problems. Additionally, students are expected to develop a portfolio of projects that can enhance their employability and readiness for industry challenges.

While the study is ongoing, preliminary feedback indicates a positive shift in students' learning experiences and outcomes. The use of PBL with VDI2206 and MATLAB System Composer has proven to be an effective approach in bridging the gap between theory and practice. The anticipated long-term outcomes include sustained improvements in student performance, increased interest in mechatronics, and a stronger alignment of academic training with industry needs.

IV. Conclusion

The students' reactions to the problem-based learning version of the course were overwhelmingly positive. They appreciated the interactive and engaging nature of the PBL approach, which allowed them to actively participate in problem-solving activities related to mechatronics system design.

These outcomes align with existing literature on the benefits of PBL, which suggests that active learning strategies improve knowledge retention and practical skills. Although the study is ongoing, the likely conclusion is that PBL, when integrated with relevant case studies and modern tools like MATLAB System Composer, effectively bridges the gap between theory and practice in mechatronics education. This approach not only prepares students better for real-world challenges but also enhances their overall learning experience and competency in mechatronics system design.

Overall, this study highlights the effectiveness of Problem-Based Learning as a pedagogical approach in mechatronics education, providing insights and recommendations for its successful implementation in similar engineering courses. By fostering active learning, critical thinking, and practical skills development, PBL holds promise for preparing the next generation of engineers to tackle the complex challenges of modern technology.

Acknowledgment

We would like to sincerely thank Xiangyun Du, Aida Olivia Pereira, and the entire Aalborg University team for their tremendous advice and assistance during the PBL pedagogical certification course. The team's ongoing supervision throughout the Mechatronics System Design course's planning, development, and implementation has aided in our students' and our own lifelong learning.

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