Comprehensive Case Study of Project Based Learning in Engineering

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Abstract

In the contemporary engineering education system, project-based learning is now seen as an innovative pedagogy that maintains the constructive collaboration of content knowledge and real-world practice. PBL exposes students to real-life problems, increases the practice of problem-solving coupled with teamwork, and the fundamental skills that are vital in the engineering field. This study consisted of four (4) projects, each projects has three (3) groups with five (5) students in each, enrolled in various engineering classes at various levels of education, including graduates and undergraduates working on the same product (portable blender) as class term project. With such student diversity, the deliverables expected from all groups turned out to be different. This research fills the gap and investigates the usage of PBL in the Lean Manufacturing class. The requirements of this project included identifying one existing product, creating an improved design, and producing a detailed business plan for the product's deployment in the market. This study aims to assess the extent to which PBL could benefit engineering students; this shall also bring out the strengths and weaknesses of the method as perceived by the students. The study's results add to the discussion of practical approaches to teaching that equip learners for the real-world challenges of modern engineering practice. Projects were piloted in the Spring semester 2024. Since each group had ten (10) consistent deliverables, like a project team charter, SIPOC, BOM, FMEA, Pareto Chart, Fishbone, VSM, Implementation Plan, Process Control and Standard Work, coordination between classes was simplified and information shared via team from each class. The students' curiosity in engineering was improved as students saw the value creation resulting from the connections with students from the other classes, their future industrial colleagues.

Keywords: Projects, PBL, Entrepreneurial Mindset, Six Sigma, graduate students

1.0 Introduction

1.1 Background

In the recent years, methods of teaching have developed and became more interactive through the incorporation of various educational approaches which immerse students in real-world problem solving, improve the hands-on experience and encourage the collaboration among students working in groups of 3 to 5. This concept comes in agreement with the definition of Project-based learning (PBL), which was defined by Barrows and Tamblyn as: The learning that results from the process of working towards understanding or resolving a problem [1].

Research indicates that PBL improves critical thinking and problem-solving abilities, essential for engineering and enhances academic achievement, retention of knowledge, and student satisfaction [2]. While effective for conveying foundational knowledge and structured information, traditional methods may fall short in developing higher-order thinking skills. Some studies suggest that traditional learning can lead to superficial understanding and lower engagement levels compared to more interactive approaches [3]

In a Lean manufacturing class, students implemented Project-Based Learning (PBL) on a real project involving a portable blender. They performed reverse engineering, redesign, and developed a business plan for market promotion. Two teams addressed the blender's components, dividing them into lower (motor, battery, control board) and upper (cup, blade, seals, shaft) subassemblies. They researched potential suppliers and ensured the design met customer demands and market competition. This project highlighted the innovative educational methods of PBL.

Projects exemplify interdisciplinary approaches where student teams from various engineering backgrounds come together to form cohesive groups. Forming a team can be challenging, however, it progresses through various stages in which students would view themselves as a group of strangers to a united team with a common goal. Psychologist Tuckman [4] provided terms for the stages of forming a group and considers it as a high-performance approach. These stages are "Forming, Storming, Norming, and Performing." Tuckman's model illustrates that as the team grows maturity and develops its capabilities, relationships are formed, and leaders adapt their leadership styles where they change from directing to coaching then participating [5].

The goal of this study is to evaluate the effectiveness of the active learning technique specifically within the framework of PBL in the context of integrated learning. Exploring the benefits of challenges experienced by the team members.

1.2 Literature Review

1.2.1 Epistemological Foundations - KEEN Entrepreneurial Mindset (EM)

1.2.1.1 Keen EM – Introduction

The Kern Engineering Educational Network (KEEN) is a network dedicated to preparing undergraduate engineering students for success, by fostering an entrepreneurial mindset in a way that develops critical entrepreneurial skills and capabilities through experiential learning that extends beyond business skills. A particular focus is placed on entrepreneurial mindset development to describe the value of entrepreneurial education for all engineering students, regardless of their career paths [6] [7]. KEEN's philosophy for an Entrepreneurial Mindset consists of three key elements, collectively known as the 3Cs: Curiosity, Connections, and Creating Value. This study intends to show how combining the engineering skillset of adding opportunity and impact to the design with the 3Cs leads to educational outcomes to develop the skillsets and mindsets of the students.

1.2.1.2 Entrepreneurial mindset (EM)

Joushua [8] presented several definitions for EM in his review work. One of the recent definitions Joshua discussed is one by Kuratko [9] which describes the entrepreneurial mindset as the true source of innovation and entrepreneurship as an ability and perspective that resides within each one of us, also consists of three distinct components: cognitive, behavioral, and emotional aspects. By incorporating this concept in projects students get to have the ability and the mindset to utilize all tools to deliver the desired value.

1.2.1.3 Curiosity

Curiosity as described by Kavale [10] is the urge to ask questions, brainstorming, showing interest, and uncovering information. All these phrases fall into the theme of curiosity. While implementing engineering projects, curiosity plays a huge role in defining the capabilities of each group to find the right information and utilize it. As part of the PBL, students are expected to explore a contrarian view of the accepted solutions.

1.2.1.4 Connection

The concept of Connections can be understood as acquiring the ability to associate and create relationships between disparate pieces of information. Students who demonstrate EM via Connections are "aware of one's own limitations in knowledge" [11]. KEEN's element of connection is to make students build their own network of information to gain insights.

1.2.1.5 Creating value.

One goal of an entrepreneur is to create economic and social value into the product to attract the customers by suggesting engineering solutions [12]. Students are expected to identify unexpected opportunities.

1.2.1.6 KEEN EM – Summary

This KEEN application project should create a robust framework by nurturing the 3Cs of Entrepreneurial Mindset: Curiosity, Connections, and Creating Value. It is expected that this application of project will provide insights to student perceptions of value toward these modules in the context of the KEEN 3Cs framework [12]

1.3 Epistemological Foundations - Project / Problem Based Learning (PBL)

1.3.1 Project / Problem Based Learning (PBL) – Introduction

In modern educational institutions, PBL is considered one of the pillars of educational foundations to prepare and encourage students for critical thinking and pursue the goal of the project of product redesign. PBL provides a unique epistemological framework that offers multifaceted benefits in the development of engineering students' knowledge, skills, and attitudes. The PBL technique provides more know-how in addition to the know-why, which fosters the 3Cs of KEEN framework.

1.3.2 Constructivist Learning theory:

The origin of PBL goes back to the Constructivist learning theory, back to 1879 the American philosopher and educator Jhon Dewey mentioned that The teacher is not in the school to impose certain ideas or to form certain habits in the child, but is there as a member of the community to select the influences which shall affect the child and assist him in properly responding to these influences [13]. This concept comes in agreement of what colleges and universities implement in their curriculum, where the professor/teacher select certain projects that will have an influence on the students alongside employing the PBL techniques to achieve the best results.

1.3.3 Social Constructivism:

As students from different engineering disciplines collectively address multifaceted problems, they initiate social interactions during learning. In projects these groups represent this social constructivism. Students build new knowledge by sharing thoughts and ideas. As per Tuckman [4] term, "Norming" stage where students begin to demonstrate cohesiveness and build a social bond, and subjective opinions are expressed.

1.3.4 Situated Cognition

Situated cognition is described that its fundamental theoretical underpinnings are congruent to PBL approaches. It also suggests that Learning context dependent and knowledge is best acquired and retained when situated within authentic tasks and environments [14] [15]. Project-Based Learning (PBL) embodies this concept by immersing students in authentic engineering scenarios. As they design and develop the drilling system and its components, students take part in activities that mirror the complexities of actual engineering practice.

1.3.5 Project / Problem Based Learning – Summary

Briefly, indulging PBL in the theme of class projects comes in agreement with the cognitive principles, including constructivist, social constructivist, and situated cognition. This epistemological grounding of PBL in class Projects establishes a solid foundation for fostering a new generation of competent and adaptable engineering professionals.

1.4 Epistemological Foundations - Interdisciplinary Projects

1.4.1 Interdisciplinary Projects – Introduction

Interdisciplinary projects in engineering education were defined as agreeing upon what skills, knowledge, and values are at play in effective interdisciplinary problem-solving and interactions, and be able to identify what counts as a contribution to interdisciplinary education by Beemt [16]

1.4.2 Integration of Diverse Perspectives

The primary epistemological upholding of interdisciplinary projects comes from the diversity of perspectives individuals have; wide range of integration can be implemented in the project framework. The integration of diverse professional expertise is essential for successful planning and execution. It outlines best practices such as forming cross-functional teams, utilizing integrated project management tools, holding regular interdisciplinary meetings, and embracing diversity [17].

1.4.3 Constructivism and Active Learning

Arik & Yilmaz conducted an analysis study using meta-analysis to study the effect of constructive learning approaches and active learning. According to the results of the random-effects meta-analysis showed that constructivist learning approach and/or active learning methods had a large and positive effect on environmental education [18]. Problem-based learning methods appear to be more effective compared to other methods that should be used more often to promote students' environmental knowledge and attitudes.

1.4.4 Contextualized Learning

Interdisciplinary projects offer students genuine learning experiences by placing knowledge in real-world contexts. Thus, in this term project students were asked to reverse engineering an existing product as if they were going to compete in the market. By addressing engineering challenges that reflect real industry scenarios, students understand the practical significance of their education.

1.4.5 Collaboration and Communication

Students cultivate crucial soft skills such as effective communication, and teamwork. These abilities are highly prized in the professional engineering field, where the success of projects frequently relies on cross-disciplinary collaboration [19].

1.4.6 Interdisciplinary Projects – Summary

Interdisciplinary projects can be abbreviated as the projects/tasks that allow students to enrich learning experiences and live the experience of a real engineering problem-solving scenario. By integrating diverse perspectives, embracing constructivism and active learning, promoting contextualized learning, and emphasizing collaboration and communication, these projects develop adaptable, creative, and socially conscious engineers capable of addressing complex global challenges.

1.4.7 Problem Statement

This case study investigates the effectiveness of integrating Project-Based Learning (PBL) with Lean Manufacturing principles within an interdisciplinary engineering education framework. The primary goal is to enhance students' technical knowledge, foster their ability to establish meaningful connections between interdisciplinary concepts, and cultivate a collaborative environment that emphasizes value creation. The study specifically examines how this integrated approach impacts students' development of critical engineering skills, problem-solving abilities, and an entrepreneurial mindset, preparing them for the complexities of modern engineering practice

1.4.8 Research Questions

This study focuses on the following objective: To investigate how PBL and Lean Manufacturing projects influenced students' educational results from two perspectives. In this investigation, the following research questions were considered:
Research Question 1: How does the integration of Project-Based Learning (PBL) with Lean Manufacturing principles enhance engineering students' ability to apply theoretical concepts to practical problem-solving, while simultaneously fostering an entrepreneurial mindset

1.4.9 Contributions of this Study

By carefully reviewing KEEN and its 3Cs of Entrepreneurial Mindset, Curiosity, Connections, and Creating Value, alongside the comprehensive scope of Interdisciplinary Projects, this study makes significant contributions to the field of engineering pedagogy. It provides a thorough analysis of how PBL promotes an entrepreneurial mindset, curiosity-driven learning, and value creating towards projects and individuals. It emphasizes the value of interdisciplinary teamwork in promoting various engineering equipment to solve real-world problems.

The contribution of this study to the on-going innovative engineering education methodologies and their potential is to equip students with the adequate tools and mindset towards the success in the contemporary engineering landscape. It provides valuable insights for educators, curriculum developers, and institutions seeking to enhance engineering education by adopting projects and entrepreneurial approaches.

1.4.10 Structure of this Study

In the remaining sections of this study, explore the Methods & Materials (Section 2.0); the Results & Analysis (Section 3.0), and the Discussion, Implications, Limitations, and Conclusions (Section 4.0).

2.0 Method & Material

2.1 Research Design

This case study utilizes the method of lean learning to implement a business plan, the main method used is DMAIC which is a structured and systematic methodology used by Six Sigma professionals for improvement and problem solving [5] combined with the project base learning methodology (PBL) which is an educational approach is known to have maximum positive impacts in producing professional competencies among student in learning process [20]. The PBL method stresses that problem solving activities are a style to gain and to apply the knowledge [1]. The purpose of this study case is to enhance the sense of curiosity towards the course, improve the connections between information and team members, and generate operational and fiscal impact and learn how to look with the customers eyes, see the value the way the customers see it. Throughout the semester, both groups implemented these tools for the realization of the project and its business plan, which led to the creation of a 3D model done with SolidWorks. By using this program, it was achieved a better visualization of the portable blender components, both the top and bottom.

2.2 Teams

For this class, four products were reverse engineered a Reacher Grabber, Pocket knife, Portable Blender, and Electrical Water Kettle. Each Product is divided into three groups of five students, totaling sixty students. The teams, consisting of graduate and undergraduate students from various engineering backgrounds, aimed to enhance knowledge transfer and learning. This setup aligns with Jiang's [21], definition of intercultural PBL teams, which involves individuals from distinct cultures collaborating to address complex real-life problems. Three groups per product were studied to evaluate their outcomes throughout the semester. The focus of this study and the provided analysis is for the portable blender projects.

2.3 Material & instruments

In this case study, students used various sources and tools to collect data. In today's internet-based world, knowledge and data are easily accessible. Pratami's research on the effect of Problem-Based Learning (PBL) on student online learning performance during COVID-19 states that students can find suitable material online if onsite classes are insufficient. Information can be sourced from platforms like Google Scholar, YouTube, and Wikipedia [22]. The Microsoft Teams was the main communication method, with each group saving time and providing flexibility.

2.4 Methods

2.4.3 Project Management

To ensure an organized learning process, each team must select a leader who will function as the project manager. This leader coordinates the individual tasks of team members to maintain effective team dynamics and timely delivery of assignments. These deliverables are submitted weekly, with a deadline of Sunday at 11:59 PM.

2.4.4 Structured Problem Solving - All Teams

Students were required to deliver weekly assignments throughout the semester, following the Six Sigma method. Six Sigma is an organized, systematic approach for strategic process improvement and new product development, using statistical and scientific methods to significantly reduce customer-defined defect rates [23]. The Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) has been used in this integrated project. This method is used in most engineering courses to fulfill the Body of knowledge of each course. The specific tools required by phase included:

Define – Team Charter and SIPOC (Supplier, Input, Process, Output Customer)
Measure – Bill of Material (BOM) and Failure Modes and Effects Analysis (FMEA)
Analyze – Pareto Chart and Fishbone / Ishikawa Diagram
Improve – Future State Value Stream Map (VSM) and Implementation Plan
Control – Process Control Plan and Standard Work Combination Table

2.4.5 Business Plan

A business plan outlines the strategic vision, operational details, and financial projections of a venture. Following Six Sigma and Lean Manufacturing guidelines, the project is divided into ten phases, grouped into five parts of the plan. This structure provides a clear roadmap and justification for the business idea. Key elements include:

a) **Part 1- Addressing the company structure and market:** in this part students were asked to write a company description that covers the product and service, problems they will be solving, targeted customers, unique value propositions – why are you better? Market analysis that shows the industry and its economic sector.
b) **Part 2 - reverse engineering the product and implementation plan:** the second part of the plan covers the product "portable blender", in which students provided facility layout, a simulation of the factory flow, CAD model design. As mentioned in section 2.4.4 students in this part were asked to deliver an element or two (2) of the DMAIC six sigma every week alongside part of the business plan. Providing a SIPOC diagram, The SIPOC modelling technique consists of a style of process documentation used in the Six Sigma framework to emphasize the sources of inputs (suppliers) and the target outputs (customers), considered a specialized approach in process modelling for improvement purposes [24], team charter, Bill of Material (BOM) and Failure Modes, Effects Analysis (FMEA), Pareto Chart, Fishbone / Ishikawa Diagram, Value Stream Map (VSM), Process Control Plan, Standard Work Combination Table.
c) **Part 3 - Marketing and sales plan:** in this part of the business plan, students covered marketing – how will they attract and retain customers? - and sales – how will they make a sale? Students provided their method own criteria in attracting and retaining customers. Students provided specific features about their products and how they are suitable for all customers. Furthermore, offering discounts and warranties. To retain customers, students offered membership to the company products providing more benefits for these members.
d) **Part 4 - Funding request:** in this part students were asked to deliver a funding request that covers how much do they need to start up their business, when do they need it, and what are the equipment used. Thereafter, a financial projection which shows income statement (1 year, by month) and another 2-5 years (by quarters). And similar balance sheet.
e) **Part 5 - Final report:** Students were asked to combine all four parts in one report as a final report following this structure:

1. Executive Summary: A concise overview of the entire plan, highlighting the business concept, market opportunity, competitive advantage, and financial projections.
2. Company Description: Background information, mission, vision, and legal structure.
3. Market Analysis: A detailed assessment of the target market, industry trends, customer needs, and competitor analysis.
4. Products: Description of the offers, unique selling propositions, and value proposition to customers. Product improvement plan using DMAIC six sigma.
5. Marketing and Sales Strategy: Outlines the marketing approach, sales channels, pricing, and promotional activities.
6. Operations and Management: Details the organizational structure, key team members, and operational processes.
7. Financial Projections: Presents projected financial statements, including income statements, cash flow, and balance sheets.
8. Funding Request (if applicable): Specifies the amount and purpose of funding required and the proposed terms for investors.
9. Appendix: supplementary information, charts, graphs, market research data, and documents.

2.5 Data Collection Plan and analysis

Students had to present quantitative and qualitative data from various sources such as Amazon, and Alibaba to compare product prices from different competitors and the cost of raw material and components to build the product from vendors worldwide. Furthermore, they analyzed customer reviews of related products to identify and avoid common defects. this undergoes the term of voice of the customer VOC, which is collecting the customer's feedback in an increasingly competitive market, collecting and analyzing VOC in real time and accurately is essential for improving customer-oriented products, as well as for providing sustainable competitive advantages for the company in the corresponding market [25]

2.6 Verification and validation

2.6.1 PBL – Verification

Project based learning technique is verified by following and fulfilling the stated requirements in section 1.3 and 1.4. This research study projects used a well-known and globally used problem solving structure, namely the Six Sigma DMAIC methodology. DMAIC is an acronym for the five (5) phases of a Six Sigma project, including Define, Measure, Analyze, Improve, and Control. Each team within each product group had the same team assignments (Deliverables) due during the same week as every other course. These Deliverables are extremely common tools in industry, including Team Charters, Pareto Charts, and Implementation Plans.

2.6.2 PBL – Validation

Following the PBL scheme, projects are validated by assessing whether the goals were met. For this class, the evaluation process involved the instructor and teaching assistant reviewing each deliverable. At the end of the semester, the final report and presentation were also evaluated by other student groups and some students from other classes who voted on the presentations.

2.7 Repeatability and Reproducibility

2.7.1 Repeatability and Reproducibility – Introduction

Repeatability refers to the consistency of measurements when performed by the same individual under similar conditions, while reproducibility pertains to the ability to achieve comparable results when different individuals or teams conduct the measurements independently. [26]. All students were asked to deliver the same set of weekly assignments, despite studying three unconventional products. With a total of sixty students, each product was assigned to three groups of five students, comprising both graduate and undergraduate students from diverse backgrounds.

2.7.2 Repeatability in Assessments

Repeatability is crucial for ensuring reliable data and conclusions in projects. Consistent measurements and standardized procedures improve accuracy and allow for replication. It supports valid engineering solutions, enhances outcome accuracy, and helps identify and correct errors.

2.7.3 Reproducibility in Integrated Project Assessments

Reproducibility fulfills repeatability by evaluating the reliability of the deliverables students ask to make when performed by different team members and groups. Projects, often involving interdisciplinary teams, must demonstrate reproducibility to establish the applicability of findings across diverse contexts. Successful reproducibility in projects implies a robust implementation of these projects, effectively fulfilling the purpose of Project-Based Learning (PBL). It fosters confidence in project outcomes, particularly when solutions need to be implemented in real-world scenarios. Emphasizing clear communication, documentation, and transparency in project methodologies and data analysis is critical to enhancing reproducibility.

2.7.4 Repeatability and Reproducibility-Summary

Repeatability and reproducibility are crucial epistemological components of Integrated Project assessments, ensuring the credibility and reliability of engineering solutions and innovations. By embracing standardized procedures, rigorous documentation, and transparency, Projects can foster a culture of replicable and dependable outcomes, paving the way for continuous advancements in engineering education and practice.

3.0 Results

As part of business implementation and in the context of engineering education and practice, the project teams conducted the redesign of the product (portable blender), focusing on establishing the product background, defining the project objectives and scope, and implementing the operational and financial goals. During the project, the teams used lean manufacturing tools to optimize the results. The SIPOC helps define suppliers research, Inputs components, Process assembly, Outputs final set up, documentation, delivery, Customers retailers/distributors, and shipping planning. For example, this is our SIPOC diagram (Figure 1)

Suppliers	Inputs	Process	Outputs	Customer
• CAD Software • CNC machine/ 3D Printer	• Initial product drawings and renders • Prototype build out	**Blender Design and Prototype Creation**	• Manufacturing issues identified • Performance data collected	• Manufacturing team • Quality control team • Marketing team
• Plastic vendor • Metal vendor • Glass vendor • Motor and electrical component vendor	• Raw materials-Plastics, Metals, Glass, Motor, Electric Components	**Material Procurement**	• Production ready process • Financial data for procurement	• Manufacturing team waiting on raw materials for next step in pull operation production
• Product Design and manufacturing engineers • Raw Materials	• Design specifications • Tolerances • Quality control instructions • CNC machines • Molding equipment	**Manufacture Blender Components**	• Completed components • Components ready for assembly • Manufacturing data for financial records	• Manufacturing/ assembly line • Line workers waiting on components for assembly in pull operation
• Suppliers • Equipment Builders	• Sub-Assemblies • Design Specifications • Assembly	**Assembly**	• Completed blenders • Ready for packaging • Ready for final inspection/testing before distribution	• Final inspection team • Packaging team • Shipping department • Logistics team
• Shipping company	• Shipping labels • Palettes • Boxes	**Packaging/ Distribution**	• En route to customer • Metrics for units shipped • Financial metrics for units sold	• Final customer • Purchasers of product

Figure 1 SIPOC Diagram

The Bill of Materials listed the suppliers and costs for each item in the portable blender, with a unit price of $28.18. FMEA was used to identify potential failure modes for the blade, motor, control board, and rubber components, leading to recommendations for corrective actions (Fig 2). A Pareto Chart, based on Amazon reviews, showed that motor issues and leaking seals were the most common defects. Fishbone analysis identified root causes such as leaking seals, motor faults, cleaning difficulties, battery drainage, and blade defects.

The VSM graph shows production control from weekly orders through material prep, scheduling, assembly, and inspections. The implementation plan covers tasks (location, permits, equipment layout, supply chain, production launch), responsibilities (management, HR, quality assurance, planning, marketing, sales), and due dates. The Process Control graph includes base assembly, blade installation, cup attachment, button installation, and quality checks. The Standard Work section details assembly components, documentation, status, release dates, descriptions, safety, parts, procedures, and testing results.
The teams analyzed to improve a better product the portable blender, achieved and created a better version of the product, and improved the process of production to reduce cost.

FMEA PRODUCT FAILURE MODE AND EFFECT ANALYSIS FORM										
PROCESS STEP/FUNCTION	POTENCIAL FAILURE MODE	POTENCIAL EFFECTS OF FAILURE	SEV	POTENCIAL CAUSES OF FAILURE	OCC	CURRENT PROCESS CONTROL	DET	RPN (SEV x OCC x DET)	RECOMMENDED ACTIONS	ACTIONS TAKEN
BLADE	DULL BLADE /BLADE BREAKABLE	PRODUCT NO WORKING	3	BLADE DULLNESS	5	VISUAL INSPECTION DURING ASSEMBLY	5	75	ENHANCE BLADE MATERIAL OR DESIGN TO IMPROVE DURABILITYAND RESISTANCE TO BREAKAGE.	COLABORATE WITH THE DESIGN TEAM TO IMPROVE BLADE MATERIAL FOR INCREASED DURABILITY
MOTOR	Motor overheating	Motor will not be able to turn the blades and would make blender useless.	8	Motor could overheat if left on too long when trying to blend foods of a harder consistency	6	Testing fan output that assists in cooling motor, as well as testing motor at max speeds with a variety of loads.	8	384	Incorporate a switch in that would shut the blender off if the torque approached it failure point.	N/A
ELECTRONIC CONTROL BOARD	short circuit	Blender not functioning correctly	9	Poor soldering or connection quality	5	Component testing during manufacturing	5	225	Improve Component Quality and Durability through rigorous testing and selection	Conduct training for assembly line workers on proper testing of the elecronic control board to reduce the risk of short circuits
RUBBER COMPONENTS	Wear and Deterioration	Rubber components were not used properly	7	poor use of material on the component	8	component tested druing manufacturing	6	336	include mutiple tests to determine the rubber components durablity	Add a process to examine the rubber comptonents integrity not to break when it is finalized

Figure 2 Failure mode and effect analysis (FMEA) Diagram

The incorporation of Project-Based Learning (PBL) to the Lean Manufacturing class strongly impacted the learners' capacity in converting the learnt concepts into critical thinking skills. For the results, performance indicators of the deliverables were used for data collection.

It was observed from the results that it can be concluded that the PBL approach really helps successfully fill the gap between knowledge and application. In practical assignments in which students were solving a problem with their hands and created a real CAD model for the portable blender product. (Fig 3). the possibilities of understanding and applying theory were also exponentially larger. This form of learning implies greater retention of information and boosts the students' confidence in what they have been learnt. This conclusion is also consistent with the performance metrics.

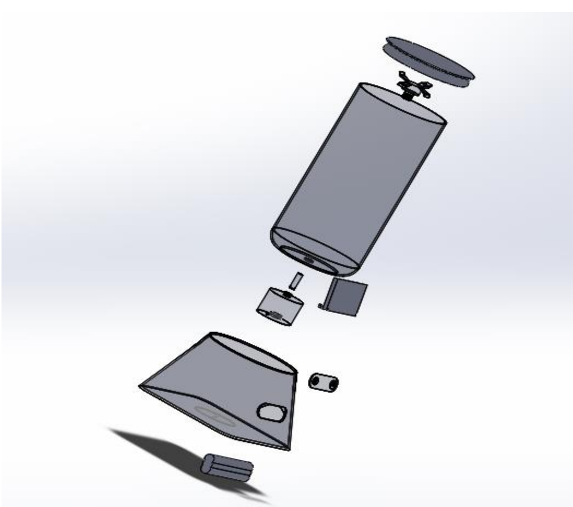

Figure 3 Exploded view of the CAD model.

4.0 Discussion
4.1 Interpretation of Results

In this case of study, several deliverables were conducted by the students fulfilling the requirements of a PBL to achieve the goal of the 3Cs of KEEN. In the case of the portable blender, the results were analyzed, the product was segmented into various parts, such as the bottom and the top. This segmentation would allow us to identify the different processes involved in the manufacturing of each component (Figure 4).

Component	Cost ($)
Motor	10.00
Battery	8.50
Control Board	5.00
Blade	2.50
Cup	3.00
Seals	1.00

Figure 4 Cost Analysis of Raw Materials and Components Table

Students broke the product into top and bottom sections to improve manufacturing visibility. The bottom includes the motor, battery, and control board, while the top has the cup, cutter heads, seals, and shaft as seen in the final assembly (Fig 5). This segmentation helps identify potential sizing issues and enhances assembly efficiency and waste reduction, optimizing the overall system.

Dividing each of the components is partitioned and serves distinctive design/manufacturing needs using segmentation. For example, this separation in levels allows us to optimize the motor end from a power consumption perspective and feature-wise for the control board without getting lost in implementation details of higher-level components. Conversely, inspecting just the tiptop permits us to spend our focus on sharpening the blade in addition to ensuring cup endurance and gasket seal integrity. In [27]A product redesign focused on manufacturing and reliability can save costs and identify key components needing attention, improving quality and reliability in specific areas.

This is also key to enabling focused verification and validation efforts. Segmenting the product allows us to critically evaluate each piece under specific conditions, making sure they meet their respective performance standards before adding them to our entire product. This approach minimizes the chance of severe rework in the final assembly if issues are identified early on during development. Redeker [28] have introduced a graph-based method of segmenting CAD models automatically for design part concept generation to achieve part-specific optimization. Focusing on each piece ensures they work efficiently, resulting in a perfectly tuned product.

Dissecting the design into components allows for in-depth analysis and testing, improving product quality and meeting market standards. Segmentation and geometry optimization also help reduce weight and cost for mass production [29]. It also improves production scalability and reduces costs, which means it is a more efficient method of the process at a lower cost have presented a modularization for product family which customized by market segment and constrained with manufacturing that saturated to optimization of profit: initiated business case. This ensures the outcome is a good fit for what the market and manufacturing methods provide, leading to an effective redesign.

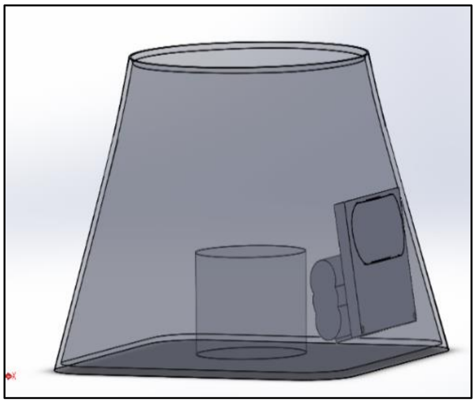

Figure 4 lower assembly

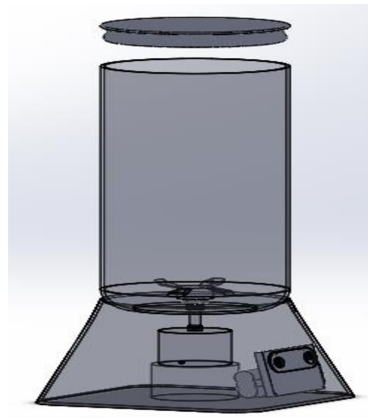

Figure 5 final assembly

4.2 Implication of Study
4.2.1 Academia

This work has far-reaching implications, both as a significant advancement for educational function and engineering practice. This work offers a scalable approach to the integration of Project-Based Learning (PBL) and Lean Manufacturing principles to enhance engineering education so students are better prepared for relevant skills that can be put into practice immediately.

The study highlights the effectiveness of PBL in developing critical thinking, problem-solving, and collaborative skills among engineering graduates. By working on real products like a portable blender, students gain both theoretical knowledge and practical experience, preparing them for professional engineering standards. This direct approach enhances student engagement and employability, as seen in software engineering. [30]. This shows that PBL is an effective way to connect education with real-world necessities, and today's brightest students are learning effortlessly.

4.2.2 Industry practice

Lean Manufacturing principles are incorporated into the PBL framework, which results in greater efficiency and less waste while fostering a culture of continuous improvement for engineering projects. The content helps students learn how to identify and eliminate waste, standardize process flow, and maximize the use of resources. This is particularly relevant in the business environment where Lean principles are widely used to improve productivity and competitiveness. An example of this is the incorporation of application-based learning related to industry best practices, including Lean in teaching, which significantly improved both generic and course-specific student experiences.

Another important insight from the study is that customer feedback really matters to product development, as evidenced by their Voice of the Customer (VOC) efforts targeted collection and analysis of publicly available data. By collecting and analyzing VOC data in real-time, students will be capable of identifying those needs and desires with their customers while focusing on decisions that define the design process leading to increased product quality accompanied by higher customer satisfaction. Of course, this customer-first approach is number one when it comes to developing successful products that sell. Real-time VOC analysis improves product design and quality based on a clear understanding of customer demand [31] This is a great demonstration of the real-world benefits of including customer feedback in academic projects.

Moreover, the research highlights interdisciplinary cooperation as a key to teaching engineering. Interacting with multi-disciplinary teams in student-led projects always promotes effective communication and teamwork-enhancing skills which enhances the ability of students to value other perspectives by instigating a collaborative blend between departments. Developing these skills is critical to responding appropriately to the complex, adaptable problems of today's engineering. Research findings have validated this by demonstrating improved teamwork and collaborative learning outcomes due to PBL [32].

The findings of this study refocus the relevance on such elements and have implications for further studying aligning PBL principles within engineering practice while incorporating concepts related to Lean into other curricula—offering significant advice in educational policy. These results may be used by educators and institutions to steer curricula development, redefining what needs to be done for future engineers to better respond to current requirements. This includes real-world projects, customer-focused feedback loops, modular design thinking, and multidisciplinary team integration. [33] described the benefit of PBL as demonstrating its benefits for intrinsic motivation and skill development, both of which clearly transfer to other contexts and have influenced curricular planning across a broad spectrum.

4.3 Limitations

This study helps towards understanding the melding Project-Based Learning (PBL) and Lean Manufacturing principles in engineering education, there are several limitations to this work that need to be recognized. These limitations could impact external validity and need to be considered when interpreting results as well as in future research planning.

The generalizability of the results should be improved by increasing both sample sizes according to products and engineering disciplines [34]. The practical implications of this study indicate that more representative samples are needed to ensure the reliability and generalizability of educational research tests across differing contexts.

Movement in this direction has taken place and continues to be verified not just by student learning gains but also career readiness, so the potential for longitudinal studies is of great interest as well; however, at this time establishing a timeline that might confirm professional gain remains elusive parameters [35].

Although students offered rich descriptions of their experiences, highlighting their perceived benefits of the PBL approach, potential bias may affect reflections and provide a good impression for the researcher. Including several types of unbiased measures such as performance-based assessments, industry evaluations, and tracking the professional accomplishments of graduates through follow-up studies can provide a more holistic evaluation of the effectiveness [36].

Overall, even though these elements provide a significant contribution to the area of study in engineering education this should be balanced with an acknowledgment of its limitations. The identification of these constraints or limitations will contribute to the work on PBL in Lean Manufacturing and with it, improve process efficiency in engineering education programs and consequently professional training for future engineers [37]

4.5 Future Research

Increasing sample size and diversity is essential; involving more students from various engineering disciplines and institutions worldwide will provide broader insights into this educational approach. Including different educational and cultural backgrounds will help understand their impact on the effectiveness of PBL in Lean Manufacturing principles [38]

A further study utilizing a longitudinal approach is required to measure the long-term impact (e.g.,) Longitudinal studies of student performance and outcomes will show how these educational practices influence professional skills, employability preparation, and career success over time. In addition, such studies could analyze methods that allow students to retain and apply the knowledge and skills learned during their working experience [39].

Finally, using external evaluations from independent industry experts in future research would enhance the credibility and relevance of study outputs. Industry assessments of students' work and project outcomes will provide an external benchmark for evaluating the effectiveness of integrating PBL with Lean Manufacturing principles. This approach ensures students are well-prepared for professional roles that require advanced engineering problem-solving skills. Such feedback is crucial for refining educational practices and aligning them with market requirements [40].

4.6 Conclusions

The results of this study suggest the substantial promise associated with employing Lean Manufacturing principles to Project-Based Learning (PBL) for effective engineering education. The approach uses practical, real-world projects to help students develop critical thinking and problem-solving skills and the teamwork ability necessary for their future jobs. This example with the portable blender shows how segmentation is applied to product design and allows modularization for specific optimization of parts.

Combining Lean Manufacturing principles in the PBL framework teaches the students to emphasize efficient use of resources, eliminate waste, and focus on process improvement. Emphasis on the Voice of the Customer (VOC) would help them perfect customer focus and produce products that are closer to what is in market demand, bringing success too.

The study does show some promising results, but it is also important to put the findings into perspective about its limitations: sample size, duration, and reliance on self-reported data. The implications are that future studies should attempt to mitigate these restrictions and examine other contexts where PBL can be used.

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5.3 Institution

Wichita State University

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