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Project-Based and Active Learning in Lean Education

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ABSTRACT: This study investigates the impact of project-based and active learning approaches in Lean education across courses. Motivated by the limitations of traditional lecture-based instruction—particularly in developing students' practical skills, critical thinking, and ability to transfer Lean concepts to real-world contexts—the redesigned curriculum integrates hands-on, industry-based projects using tools such as value stream mapping (VSM), SMED, process data collection, and standardized work. An exploratory assessment was conducted through course evaluation surveys administered between 2023 and 2025, comparing student responses before and after the implementation of project-based learning. Results from undergraduate and graduate students show substantial improvements in teamwork, creativity, critical thinking, problem-solving initiative, project management, and depth of conceptual understanding. Students in the project-based courses reported markedly higher positive responses, particularly in critical thinking and effective use of team strengths. However, findings also indicate the need for instructors to provide clearer learning goals and additional resources to support independent learning. Overall, the study demonstrates that project-based and active learning significantly enhance student engagement, motivation, and Lean competency development. Future work will expand project customization for multidisciplinary cohorts and extend these pedagogical strategies to additional engineering and management courses.

KEYWORDS: Active learning, Lean education, Project-based learning, Student-centered learning

INTRODUCTION

Lean education—whether in lean manufacturing, lean six sigma, or lean operations—aims to cultivate the capability to identify waste, improve flow, and deliver customer value through systematic problem solving. In the last five years, the pedagogical question has increasingly shifted from what lean tools to teach to how to teach them so that learners can transfer concepts into practice. Project-Based Learning (PBL) has been increasingly adopted in engineering and manufacturing education, particularly in teaching lean enterprise and manufacturing concepts. Research demonstrates that PBL is beneficial for students to enhance practical understanding, student engagement, and interdisciplinary collaboration. Studies have highlighted that PBL engages students in real-world problems, improving teamwork and problem-solving skills, which are essential for lean practices [11]. Projects often include deliverables such as SIPOC diagrams, value stream maps, FMEA, Pareto charts, and standardized work, all of which mirror industry requirements [24].

Through real and structured projects, the students not only acquire technical competencies but also develop essential soft skills such as project management, teamwork, and communication. Empirical work demonstrates that integrating semester-long, industry-based projects into lean courses significantly improves students' comprehension and application of lean tools. Students apply theoretical lean knowledge and tools in real company settings will result in measurable improvements in understanding. A comprehensive case study in 2024 showed increased student motivation, curiosity, and coordination across interdisciplinary teams when PBL was embedded in lean enterprise and manufacturing coursework [1].

Thus, the purpose of this study is to conduct an exploratory investigation aimed at enhancing students' skills through project-based learning, specifically targeting groups of lean enterprise and manufacturing students. Project-based learning with hands-on activities has been incorporated into the courses Lean Enterprise (INMGT-440/640) and Lean Manufacturing Systems (INMGT-335). These courses place greater emphasis on the application of lean tools and implementation rather than solely on theoretical analysis. Furthermore, integrating project-based learning through semester-long and industry-based projects encourages students to collaborate in teams and apply the knowledge they have acquired to solve practical problems.

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LITERATURE REVIEW

Project-Based Learning (PBL) has increasingly become a preferred pedagogical approach in engineering and manufacturing education. Defined as learning through problem-solving and sustained project work, PBL immerses students in realistic scenarios that mirror industrial challenges. This aligns particularly well with Lean education, where hands-on application, process analysis, waste reduction, and continuous improvement are essential competencies. Recent research shows growing interest in integrating PBL into Lean Manufacturing courses to improve conceptual understanding, practical skills, and student engagement [1].

PBL's defining characteristics—authentic problems, sustained inquiry, collaborative work, iterative design, and a tangible deliverable—mirror the logic of lean improvement cycles. Curriculum arguments in higher education increasingly frame PBL not as an "add-on activity," but as an integrative thread that connects theory, practice, skills, and professional identity development across a program [20]. For lean specifically, this integration matters because many lean tools (e.g., value stream mapping, standard work, pull systems) are inherently contextual and systems-dependent; learning them as isolated techniques risks superficial understanding. Studies in engineering PBL reviews also emphasize that PBL's strengths appear when projects approximate real professional complexity—often requiring interdisciplinary coordination, tradeoffs, and the use of professional tools and documentation practices [6].

Lean Manufacturing concepts—including value stream mapping (VSM), standardized work, 5S, FMEA, and process control—require more than theoretical instruction. Traditional lecture-based approaches often fall short in enabling students to fully understand complex, dynamic production systems. Some studies have been conducted to investigate the implementation and impact of Project-Based Learning (PBL) on students' technical competence, teamwork abilities, and readiness for industry by replacing traditional lecture-based methods with project-centered instruction [2-3]. Prabhu et al. (2025) demonstrates that the PBL approach effectively improved student learning, skill development, and employability in the CIM course and it also supported the integration of theory and practice, increased engagement, and met accreditation expectations. They also point out that successful implementation requires resources, instructor expertise, and careful project design [2]. Simulation-based PBL approaches can further reinforce Lean principles by helping students understand process flow, variation, and improvement cycles. Project-based work involving machining, digital manufacturing, or CAM/CNC integration strengthens Lean learning, especially as Lean and Industry 4.0 practices converge [3]. Another recent direction is the blending of PBL with Lean Six Sigma (LSS) frameworks, especially in domains where the "process" is digital rather than physical. Money and Mew (2023) propose combining PBL and Lean Six Sigma to teach Robotic Process Automation (RPA) development and systems integration. Their core argument is that PBL fits naturally with LSS because learners must document current processes, define desired future states, and apply structured improvement logic to achieve measurable benefits [7]. This line of work is important for two reasons. First, it signals that lean education is not confined to shop-floor manufacturing: lean thinking and LSS tools increasingly support service and information processes. Second, it suggests that PBL can be a bridge for students who may not yet recognize the relevance of lean tools until they enact them within a realistic project that produces traceable outcomes (time, quality, volume) [21]. Although these publications emphasize methodology proposal and instructional design, they contribute to the growing pattern that structured improvement frameworks (DMAIC, SIPOC, VSM) become more meaningful when embedded in an open-ended project rather than taught as isolated steps [7].

One robust thread in recent work is simulation laboratories designed to teach lean concepts through experiential cycles of "before" and "after" process states [22]. A notable example is the development of a lean manufacturing simulation laboratory for continuing education students, which reports improved student performance after incorporating simulation exercises aligned to course outcomes. This type of design is consistent with how lean is learned in practice: learners observe current performance, diagnose bottlenecks and wastes, apply countermeasures, and evaluate outcomes [8]. PBL in lean education is also visible in workforce development and professional upskilling. An ASEE 2025 paper on upskilling manufacturing professionals through PBL in Industry 4.0 technologies reports that project-embedded learning delivered tangible organizational benefits, including major cost savings, while bridging skill gaps through real implementation rather than classroom abstraction [23]. While this work is framed under smart manufacturing, its underlying mechanism aligns with lean: value creation through systematic problem identification, solution development, and measurable operational impact—achieved through authentic projects in context [9].

Some substantial benefits of Project-Based Learning (PBL) have been identified. Literature in engineering pedagogy emphasizes that PBL provides authentic engagement with real-world problems through design, analysis, and iterative refinement [4]. PBL contributes a deeper understanding of systems thinking, which is critical for Lean's holistic view of waste and value [5]. In addition, PBL provides opportunities for collaborative problem-solving, mirroring the team-based nature of Lean implementation [3]. These characteristics make PBL an ideal match for Lean Manufacturing instruction. Although PBL offers substantial benefits, challenges include increased instructor workload, resource demands, interdisciplinary coordination, and variations in student preparedness. Nevertheless, the literature consistently concludes that PBL is a highly effective pedagogy for preparing future engineers for real-world Lean Manufacturing environments.

MATERIALS AND METHODS

Lean education (whether in lean manufacturing, lean six sigma, or lean operations) today demands more than analytical problem-solving and calculation; it requires immersive engagement with design, creativity, and innovation [25]. To achieve this in lean education, curricula are innovating by integrating lean tools and , industry-based projects. These tools facilitate an active-learning environment where students experience the full lifecycle of robotics and control system design and development. This approach broadens exposure to emerging technologies and equips future managers and engineers for real-world challenges. Consequently, students can enhance their hardware/software proficiency, comprehensive application skills, practical abilities, and innovative thinking. Furthermore, these project-driven experiences cultivate teamwork, communication, leadership, and ultimately, employment competitiveness. Two dedicated project-based courses have been implemented to achieve these objectives.

Example projects

(1) Value Stream Mapping (VSM) & Lead Time Reduction Project

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One of the projects is to map a process end-to-end, quantify lead time and waste, then design a future-state VSM with improvements to reduce lead time and WIP. The learning outcomes of this project are to collect and analyze process data (cycle time, waiting, inventory, information flow), create current- and future-state value stream maps, and propose and justify improvements using Lean principles (flow, pull, takt). The following step-by-step instructions are recommended to the students: (a) Select a process and define start/end points (e.g., order-to-ship, lab request-to-results); (b) Collect data for each step: cycle time (CT), waiting time, changeover, # operators, uptime %, WIP/inventory between steps; (c) Create a Current-State VSM as shown in Figure 1 including: process boxes, data boxes, inventory triangles, information flow and scheduling method; (d) Calculate current totals: total processing time vs total lead time; identify bottlenecks and main sources of waiting/WIP; (e) Identify wastes using TIMWOOD (Transportation, Inventory, Motion, Waiting, Overproduction, Overprocessing, Defects); (f) Design a Future-State VSM: propose changes (Kanban/pull, WIP caps, supermarkets, cell layout, heijunka, SMED, standard work); (g) Quantify expected improvements (lead time %, WIP reduction, throughput or on-time delivery improvement); (h) Create an implementation plan (who/what/when) with 3–5 prioritized actions and risks/assumptions. Required deliverables include current-State VSM, data table (CT, wait, WIP) and calculations, waste analysis summary, future-State VSM, and improvement plan with quantified impact. Students are expected to critically engage with the project. Teams can achieve dramatic lead time reductions by addressing the most critical sources of delay and inventory accumulation. They are expected to reflect, evaluate, and make decisions by themselves.

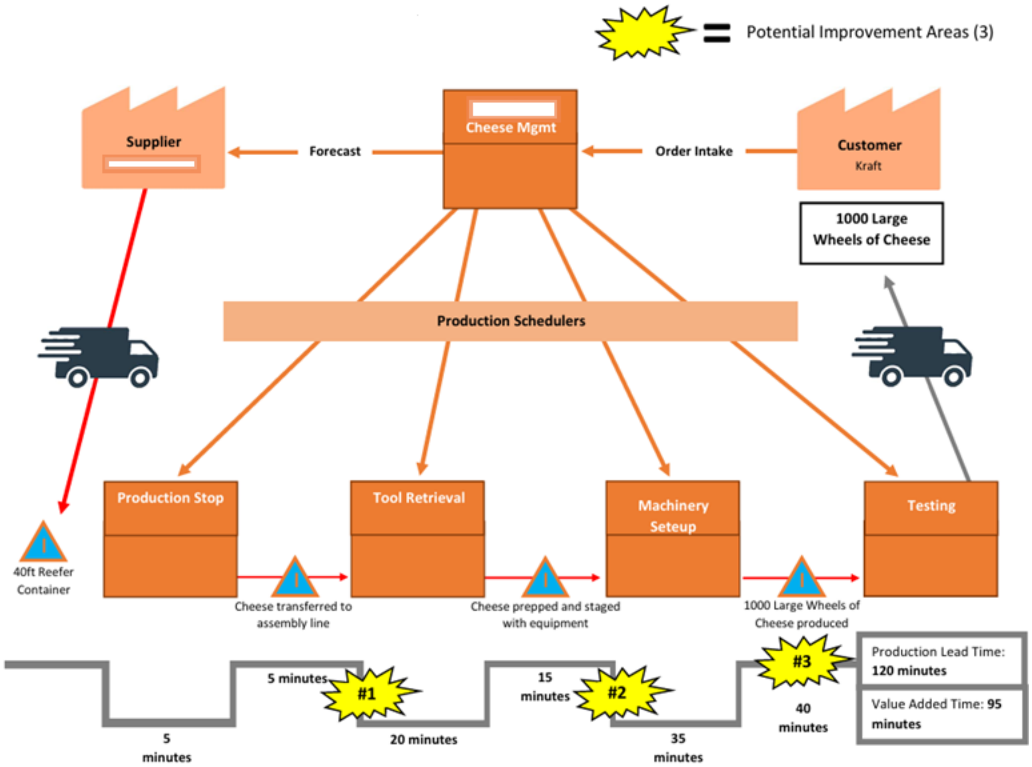

Figure 1. Current-State VSM example

(2) Single-Minute Exchange of Die (SMED) Project

The purpose of Single-Minute Exchange of Die (SMED) is to reduce setup/changeover time by converting internal steps to external, simplifying tasks, and standardizing the procedure. The learning outcomes of this project are to conduct a time study and decompose a setup into discrete steps, classify steps as internal vs external and apply SMED principles, and design standard work and quantify time reduction. The following step-by-step instructions are recommended to the students: (a) Choose a process with changeover/setup (such as 3D printer job change, laser cutter setup, CNC tool change, packaging changeover); (b) Record the current setup (video if allowed) or time-study and create a step list with timestamps; (c) Classify each step as INTERNAL (requires stoppage) or EXTERNAL (can be done while running); (d) Identify improvement opportunities: convert internal to external, reduce motion, use kitting, presets, quick releases, checklists, point-of-use tools; (e) Implement feasible changes; (f) Run the improved setup at least once and record the new time and compare with baseline; (g) Create a standardized setup procedure (standard work) with photos/diagrams if possible; (h) Report results: before/after time, % reduction, what changed, limitations, next steps; (i) Submit a 2–3 page report with the SMED table and standard work. Required deliverables include: Baseline time study (step list with times), SMED classification table (internal/external), Improved setup procedure (standard work + checklist), Before/after comparison with % reduction; Short reflection and next steps. An example of project is shown in Figure 2.

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Figure 2. Before/After SMED Project Example

Assessment of project-based and active learning

An evaluation of project-based learning is conducted through a course evaluation survey to assess its performance, advantages and drawbacks in order to evaluate the competences or skills obtained by the students through the application of project-based learning. Course evaluation survey was distributed to the students at the end of semester by using online questionnaires and it was carried out and treated confidentially. The samples comprised undergraduate students majoring in B.S. in Manufacturing Engineering, B.S. in Plastic Engineering, B.S. in Management, B.S. in Automation Leadership programs, and graduate students majoring in M.S. in Manufacturing Engineering and M.S. in Construction Management programs during academic year from 2023 to 2025. Students during academic year 2023-2024 took a more traditional "lecture-based" course, prior to the implementation of project-based and active learning. Students during academic year 2024-2025 studied the transformed course involving project-based and active learning.

During academic year from 2023 to 2025, a total of 44 students were asked to complete course evaluations with 100% response rate. Among these 44 students, 24 students were undergraduate students and 20 students were graduate students, 20 students were from academic year 2023-2024 academic year and 24 were from 2024-2025 academic year. The survey was published online after the student completed the course. Students participated via a consent form, and all responses were anonymous. The course evaluation questionnaire consisted of ten questions. Students responded using a 5-point Likert scale, where "strongly agree" and "agree" were considered to represent a positive attitude, whereas "disagree" and "strongly disagree" were considered to represent a negative attitude.

RESULTS

Table 1 and 2 shows the results of students' responses on traditional lecture-based learning during academic year 2023-2024 and the new project-based and active learning adopted during academic year 2024-2025. According to student responses for Q1 "I had a great team working experience in the course", The course during academic year 2024-2025 (75%) received 30% more positive feedback compared to 2023-2024 (45%). There is significant improvement regarding student learning experience after the implementation of project-based learning.

Table 1. Results of students' responses on lecture-based course during 2023-2024

Students Responses (2023-2024)	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Q1. I had a great team working experience in the course.	10%	15%	30%	30%	15%
Q2. The instructor clearly presented the learning goals and requirements.	5%	10%	20%	40%	25%
Q3. I demonstrated creativity in my approach.	15%	10%	40%	20%	15%
Q4. Our team used each member's strengths effectively.	10%	15%	50%	15%	10%
Q5. I managed my time effectively to meet deadlines.	10%	10%	25%	30%	25%
Q6. I took the initiative in researching and solving problems.	20%	15%	25%	30%	10%
Q7. I used critical thinking to analyze information.	0%	5%	30%	30%	35%
Q8. My final product demonstrates deep understanding of the topics.	10%	5%	30%	30%	25%
Q9. Resources (materials, tools, information) were sufficient.	0%	5%	25%	50%	20%
Q10. I received helpful guidance and feedback from my teacher.	0%	0%	20%	40%	40%

Table 2. Results of students' responses on project-based course during 2024-2025

Students Responses (2024-2025)	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Q1. I had a great team working experience in the course.	0%	4%	21%	33%	42%

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Q2. The instructor clearly presented the learning goals and requirements.	13%	13%	42%	21%	13%
Q3. I demonstrated creativity in my approach.	4%	4%	21%	50%	21%
Q4. Our team used each member's strengths effectively.	0%	4%	17%	33%	46%
Q5. I managed my time effectively to meet deadlines.	0%	0%	17%	33%	50%
Q6. I took the initiative in researching and solving problems.	0%	4%	21%	33%	42%
Q7. I used critical thinking to analyze information.	0%	0%	8%	42%	50%
Q8. My final product demonstrates deep understanding of the topics.	0%	4%	17%	33%	46%
Q9. Resources (materials, tools, information) were sufficient.	4%	8%	25%	42%	21%
Q10. I received helpful guidance and feedback from my teacher.	0%	0%	21%	33%	46%

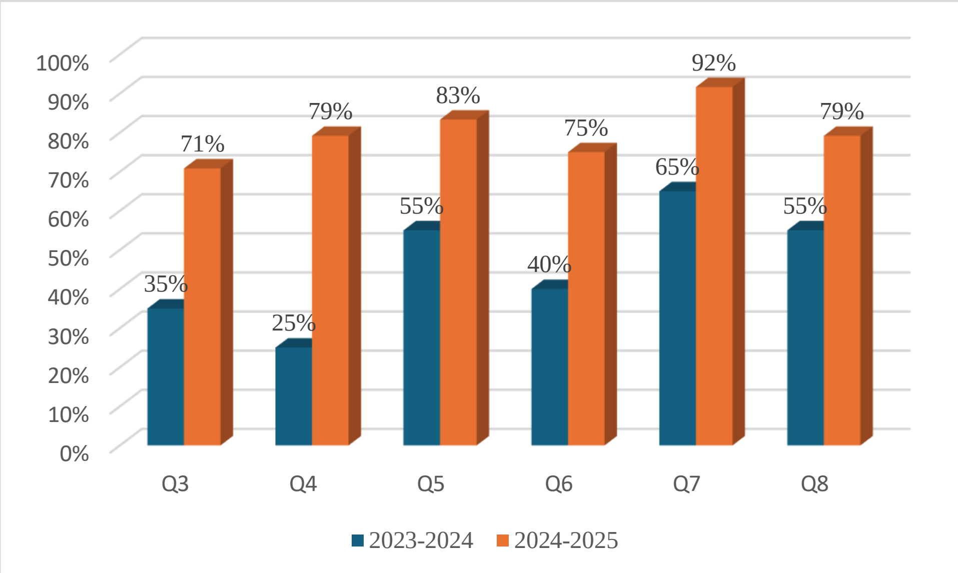

Figure 3. Comparison between traditional lecture-based and project-based learning.

Figure 3 shows the comparison between traditional lecture-based (2023-2024) and project-based learning (2024-2025) regarding the improvement of students' creativity, strength utilization, project management skill, research initiatives, critical thinking, and the understanding of topics, which is supported by some studies [10-18]. Dias-Oliveira et al. (2024) verified that project-based learning approach can improve students' skill of critical thinking, communication and team working based on the research results of Multidisciplinary Project course (MPI) [12]. According to the student responses for Q7 "I used critical thinking to analyze information" and Q4 "Our team used each member's strengths effectively", project-based learning increased positive feedback from 65% to 92% and from 25% to 79% respectively. Based on the student responses for Q6 "I took the initiative in researching and solving problems", the course during academic year 2024-2025 received around 75% positive feedback in comparison to lecture-based learning 2023-2024 (40%). It indicates that project-based learning is helpful for the students to develop their ability in research and problem-solving, which is consistent with previous studies [11]. Faozi et al. (2020) proposed that project-based learning by solving different problems is possible to develop creative ideas while increasing highly developed skills. Jiang and Pang (2023) pointed out that project-based learning (PBL) is an effective lean education method to improve students' design thinking, lean application, and innovation abilities and creativity in terms of adventure, curiosity, imagination, and challenge [14]. It has been proposed that students should be trained by the instructors based on their professional skills and real-time experience to prepare students for real time environment upon graduation to meet industry needs [16]. Jamilurahman et al. (2021) presented an educational framework for the implementation of project-based learning with industry collaboration to reduce the gap between both parties by training students with real-time projects and market-oriented aspects, which is not seen in the traditional approach. Moreover, it helps students to gain complete knowledge of lean concepts, hard and soft skills, design process and principles with more confidence over real-time projects [16]. Some studies support that students can gain hands-on expertise in interdisciplinary problem-solving and stakeholder-driven projects through project-based learning [17]. By implementing project-based learning, lean education will bridge theoretical learning with applied innovations, equipping the students with competencies critical for product development. In addition, some scholars highlight the positive impact of project-based learning, which can improve students' comprehension and enhance critical thinking, collaboration, creativity, and communication skills [18].

However, survey results also demonstrate some advantages for traditional lecture-based teaching, which could be considered to improve project-based teaching in the future. Based on the student responses for Q2 "The instructor clearly presented the learning goals and requirements" and Q9 "Resources (materials, tools, information) were sufficient", the course during academic year 2023-2024 received around 30% and 10% positive feedback respectively in comparison to project-based learning implemented during 2024-2025. These results indicate that the students expect the teachers to present teaching materials in a traditional lecture-based approach. Similarly, less resources were provided by the instructor in project-based learning, which means that the students will need to do more self-learning to complete the projects. When taking these two responses into account, we found that project-based learning pushes students beyond their traditional learning boundaries and encourages independence while

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working on the projects. Some studies have explored the roles of instructors in project-based learning [19]. As the designer, the instructors need to develop real-world projects aligned with learning outcomes by collaborating with industrial companies and integrating core knowledge and theory into project tasks to motivate student learning and enhance their learning performance. Therefore, some changes should be made in the teaching approaches by providing students with more theoretical knowledge and support for independent learning before starting the projects.

CONCLUSION

This study has highlighted the concerns regarding lecture-based teaching in lean education. Our innovative project-based curriculum was developed to replace it with project-based learning. The results of this study show that project-based and active learning in lean education encourages the students to think critically, learn from each other via working in group, discuss, gain valuable skills in communication, project management and leadership, and especially learn actively. There is significant improvement regarding student learning experience after the implementation of project-based learning. It shows that students talked about how project-based and active learning courses change their views of lean tools and their applications. It also shows that proposed projects have great impacts on motivate students' learning interests and enthusiasm for lean. Furthermore, student's skills with lean practices, comprehensive application and hands-on abilities, and creativity can be better cultivated, as well as professional abilities of teamwork and leadership. In addition, the instructor need provide students with more theoretical knowledge and support for independent learning before starting the projects to further enhance the performance of active learning.

For future research, we would like to continuously improve the course-related projects based on the students' feedback. More customized projects for students from diverse disciplines will be developed to facilitate multidisciplinary collaboration. Moreover, we also would like to extend project-based learning to more interdisciplinary courses in management and engineering education, even the students from different backgrounds or majors, since the surveys in this study were only completed by 44 students. Nevertheless, survey data clearly supports that proposed project-based and active learning has significant positive impact on student learning experience.

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