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Bridging Academia and Industry: Development of Requirements Engineering Competencies through Project-Based Learning

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Abstract

Project-Based Learning (PBL) has emerged as a powerful pedagogical approach to enhance active learning and develop essential competencies in higher education. In the industrial engineering department at the Federal University of Rio Grande do Sul, undergraduates are expected to be capable of designing sustainable solutions that meet the demands of different stakeholders simultaneously, making requirement engineering competence essential. This study investigates the effectiveness of PBL in developing Requirement Engineering (RE) competence in the Design of Sustainable Project-Service System Solutions (DSPSS) course. That course was introduced into the program in 2021 and employs PBL to engage students in real-world challenges proposed by partner companies, focusing on integrating sustainability with product-service systems. Through self-assessments, course evaluations, and industry feedback, this research assesses the adoption of PBL for developing problem-solving, requirement analysis, collaboration, and communication competencies. The findings indicate that PBL effectively enhances students' technical and transversal competencies, bridging the gap between academic learning and industry demands. Furthermore, the study highlights the importance of continuous feedback and industry collaboration in optimizing learning outcomes. These results contribute to the ongoing discussion about the role of active learning in engineering education, reinforcing the value of PBL to developing future-ready engineers qualified in RE competencies and sustainable innovation awareness for better decision-making processes.

Keywords
Project-based Learning, Industrial Engineering Education, Requirements Engineering Competencies, Sustainable Integrated Solutions.

1. Introduction
Active learning practices have effectively engaged higher education students and fostered higher-order cognitive competencies across multiple disciplines (Baepler et al. 2014; Monteiro et al. 2017; Li et al. 2019; Patel et al. 2019; Ferreira and Canedo 2020). Research in engineering education demonstrates various successful implementations of active learning practices (Hartikainen et al. 2019; Otero et al. 2020; Corrêa et al. 2023), demonstrating their potential to develop critical competencies for future engineers. Project-based learning (PBL) is a systematic practice that enables students to build knowledge and develop competencies actively (Thomas 2000; Pereira et al. 2017). Investigative tasks help students address technological, social, and basic curriculum content. The literature suggests that PBL is generally more effective than traditional lecture-based approaches in higher education (Cheng and Yang

2019; Guo et al. 2020). However, some studies indicate comparable learning outcomes between these approaches, as Jollands et al. (2012) demonstrated.

In undergraduate engineering programs, PBL fosters meaningful learning experiences by integrating theoretical knowledge with practical applications and promoting the development of essential professional competencies (Karim et al. 2019; Parrado-Martínez and Sánchez-Andújar 2020). Most studies on PBL focus on undergraduate engineering courses (Pereira et al. 2017; Monteiro et al. 2017; Kuppuswamy and Mhakure 2020), emphasizing real-world projects that address industry challenges (Dinis-Carvalho et al. 2017). However, there is a need for further research on how PBL can enhance undergraduate Industrial Engineering (IE) programs, particularly in bridging academic learning with industry requirements.

Requirements Engineering (RE) competencies are crucial for professionals designing product and service solutions (Holtkamp et al. 2015). In Industrial Engineering, RE competence enables a deep understanding of customer needs and effectively translates these needs into well-defined and feasible requirements. Managing complexity, uncertainty, and changes require technical expertise and transversal and adaptive competencies. Thus, undergraduate IE students must acquire these competencies through innovative pedagogical practices, active learning, and industry collaboration to prepare them for the complexity of modern engineering practice (Jantunen et al. 2005; Jantunen et al. 2019). Key competencies for future RE practitioners include project management, problem-solving, leadership, communication, research, and sustainability (Jollands et al. 2012; Jantunen et al. 2019).

Addressing contemporary challenges, such as developing integrated and sustainable product-service solutions, requires leveraging diverse methods and balancing technical and transversal education while fostering creativity and problem-solving competencies (Chang et al. 2015; Silveira et al. 2022). That demands a comprehensive course design that connects theory with real-world applications. The Design of Sustainable Project-Service System Solutions (DSPSS) course was introduced in the IE undergraduate program in 2021. Its challenge was to provide IE undergraduates with technical and transversal RE competencies. The course employs PBL to involve students in addressing the challenges of the partner companies. It focuses on innovating and increasing sustainability in product-service systems, taking it to the next level.

DSPSS should develop these key competencies: (i) identifying and solving complex problems by designing integrated solutions that address stakeholder needs; (ii) collecting and analyzing requirements while embedding sustainability from the early design stages; and (iii) collaborating effectively, ensuring clear communication within the team and with external stakeholders (Jollands et al. 2012; Jantunen et al. 2019). This study contributes to existing literature by investigating the application of active learning practices in undergraduate education. Specifically, it presents the results of implementing a PBL-based practice to develop RE competencies in an undergraduate IE program at the Federal University of Rio Grande do Sul (UFRGS). This study also examines four years (2021–2024) of PBL implementation in DSPSS, assessing its impact on competency development from course evaluations and students' self-assessments.

1.1 Objectives

This study aims to investigate the application of PBL in undergraduate IE education, specifically for developing RE competencies. The objectives of the research are:

- To assess the effectiveness of PBL in enhancing students' ability to identify and solve complex problems by creating integrated product-service solutions that address stakeholder needs.
- To evaluate students' ability to collect and analyze requirements while incorporating sustainability concerns from the early stage of design.
- To examine the impact of PBL on students' collaboration and communication competencies, both within teams and with external stakeholders.
- To analyze students' self-assessments and course evaluations to determine their perceived learning outcomes from the PBL experience.
- To collect the industry's perception of the problem-solving process and the feasibility of the students' proposed solutions.

2. Theoretical Background

Applying PBL in IE education has been studied as an effective strategy for developing essential competencies in RE. Grounded in constructivist theories such as Kolb's Experiential Learning (Kolb 1984) and Lave and Wenger's Situated Learning (Lave and Wenger 1991), PBL encourages students to solve complex problems by creating integrated product-service solutions that address stakeholder needs (Thomas 2000; Jollands et al. 2012). Moreover, recent literature highlights the importance of incorporating sustainability principles from the early stages of requirements development, emphasizing the need for a structured data collection and analysis approach that enables the effective integration of these aspects into the project (Chang et al. 2015; Silveira et al. 2022).

Another central factor in applying PBL to IE is its influence on developing collaborative and communication competencies, which are essential for professional practice. Studies indicate that PBL fosters interaction among team members and strengthens students' ability to communicate with external stakeholders, leading to solutions that are better aligned with industry demands (Jantunen et al. 2019; Corrêa et al. 2023). However, challenges remain in assessing the impact of this methodology, both from the student's perspective—through self-assessments and institutional feedback—and from the market's viewpoint, which must validate the feasibility of proposed solutions. Therefore, research integrating industry perspectives into the teaching-learning process is crucial to ensuring that PBL effectively contributes to training engineers who are better prepared for contemporary challenges (Dinis-Carvalho et al. 2017; Pereira et al. 2017).

The integration of PBL into undergraduate IE curricula has been increasingly recognized as an effective pedagogical approach to fostering the competencies needed in RE. According to Kolb's Experiential Learning Theory (Kolb 1984) and Lave and Wenger's Situated Learning Framework (Lave and Wenger 1991), PBL allows students to actively engage in knowledge construction, solving real-world problems while developing both technical and transversal competencies. This experiential approach is particularly beneficial in the context of RE, as it promotes the design of integrated product-service systems that consider stakeholder needs from a sustainability perspective (Chang et al. 2015; Silveira et al. 2022). Moreover, recent research emphasizes the importance of embedding sustainability into the early stages of requirements gathering and analysis, urging students to approach problem-solving with a comprehensive understanding of technical requirements and social implications (Jantunen et al. 2019; Dinis-Carvalho et al. 2017).

Furthermore, PBL has been shown to enhance collaborative and communication competencies, which are crucial in professional practice. By working in teams and interacting with external stakeholders, students refine their ability to present and defend solutions, leading to outcomes more aligned with industry needs (Jantunen et al. 2019; Corrêa et al. 2023). This collaborative dynamic is essential in bridging the gap between academic knowledge and real-world industry practices. However, challenges remain in assessing the effectiveness of PBL in this context. While students' self-assessments and course evaluations offer valuable insights into their learning experiences, the inclusion of industry feedback is vital to ensuring that the solutions developed are not only innovative but also practical and feasible within the real-world industrial landscape (Dinis-Carvalho et al. 2017; Pereira et al. 2017). Therefore, the continued investigation of PBL's impact, from both the academic and industry perspectives, remains a critical area for future research in Industrial Engineering education.

3. Procedures and methods

The Design of Sustainable Project-Service System Solutions (DSPSS) course is offered as an elective course for ninth-semester students in the IE program at the Federal University of Rio Grande do Sul (UFRGS), which has a total duration of 10 semesters. The course is organized over 18 weeks with a workload of 60 hours (4 credits) with one 4-hour class per week, totaling 15 hours of synchronous activities and 45 hours of asynchronous activities.

Synchronous activities encompass lectures, case study presentations, discussions, and collaborative work on the applied project. Asynchronous activities encompass research and data collection, the reading and analyzing of case studies, and collaborative efforts on the applied project. The course has been available each semester since 2021. The PBL practice, in collaboration with companies and utilizing the R-PSS method (Requirements Engineering for PSS Solutions) (Echeveste et al. 2020; Lermen et al. 2020; Lago et. al 2021) has been in effect since 2021. The R-PSS method, grounded in constructivist research and validated through practical applications (Lermen et al. 2020; Lago et. al 2021; Tinoco et al. 2023; Borin et al. 2023), synthesizes concepts and tools from various disciplines to propose sustainable Product-Service System (PSS) solutions. The R-PSS Method consists of three primary phases. **Phase 0** initiates the process by concentrating on problem definition and preliminary structuring. This phase entails identifying the problem concerning the business model and value proposition, employing tools like Lean Canvas. It also encompasses PSS classification, life cycle analysis, and stakeholder identification. The concept may require pivoting before advancing to the subsequent stage.

Phases 1 and 2 focus on analyzing and defining requirements, which include eliciting and categorizing needs from various perspectives. Customer-related requirements are prioritized, and potential conflicts are assessed. Requirements are identified and prioritized based on their significance. Furthermore, essential processes are delineated and optimized to guarantee efficiency and practicality. Trade-offs are assessed to reconcile various demands and constraints. **Phase 3** ultimately emphasizes the development of a sustainable solution, organized into three distinct steps. The PSS concept is developed utilizing a PSS blueprint, which is succeeded by a concept description illustrated via a System Map. The final step involves validating the concept using a prototype created with virtual prototyping tools. The method integrates an evaluation of the solution's economic feasibility and contribution to sustainability throughout the process. The course's main objective is to integrate theory and practice, providing students with realistic experience in solving real-world problems that local companies or startups face.

To achieve this, students, organized into groups of 3 or 4 members, develop conceptual solutions for challenges proposed by partner companies, focusing on sustainability and aligning with PSS business models. This approach enables students to apply multidisciplinary knowledge and experience in the design and development process of integrated product and service solutions, contributing to their professional development and preparation for the job market. In the first class, the approach adopted in the course is presented, along with the evaluation methods and respective assessment criteria. During this session, the fundamental concepts of the practice are introduced, and the activity schedule is detailed, as summarized in Table 1. From the third session onward, the challenges proposed by partner companies are presented, and the groups that will work on these challenges are formed.

Table 1. Course Structure

Week	Stage of Project
1	Project introduction and initial orientations
2	Definition of the current business model and stakeholder analysis
3 to 5	Demand identification and definition of the new value proposition
6 to 9	Requirements prioritization -RE and sustainable contribution assessment
10 to 12	Design of the concept and processes of the sustainable PSS and economic-financial assessment
13 to 15	Prototype development
16 to 18	Validation and business plan

Based on the RE competencies defined for the course (technical and transversal), the assessment instruments and active learning pedagogical practices are outlined. PBL is the primary method, as shown in Table 2. This alignment between expected student competencies, pedagogical practices, and assessment instruments follows the Backward Design approach for competency-based course design (Reynolds and Kearns 2017).

Table 2. Alignment of competencies, practices, and assessment

Type	Competencies to be developed	Active learning practices	Assessment instruments
Technical	Ability to identify and solve complex problems through the design of integrated product and service solutions, considering the requirements of multiple critical stakeholders	PBL Interaction with companies Group work Collaborative Learning	Partial deliveries, Business Plan, and developed prototype Pitch gives the proposed solution and evaluation of the companies
	Ability to collect and analyze relevant requirements and consider sustainability aspects in the integrated solution project, from the initial phases of the development process		
Transversal	Ability to work as part of a team, encouraging effective communication of ideas and solutions with team members and external stakeholders involved in the project	PBL Interaction with companies Group work Collaborative Learning	360º Evaluation: Self-assessment Team evaluation Company evaluation Professor's evaluation

Learning assessment is a continuous process throughout the project using formative assessment (Gervais 2016; Guerro-roldán and Noguera 2018; Tinoco et al. 2023). In this case, formative assessment was conducted through feedback from professors and partner companies on the progress and partial results of the method's implementation and business plan discussed in groups. On the other hand, summative assessment (Gervais 2016; Guerro-roldán and Noguera 2018) involved the submission of the business plan, the prototype developed for the proposed solution, and the final presentation (defense) of this solution to representatives of the partner companies. The summative assessment also included a 360º evaluation, considering self-assessment by students, peer evaluation, evaluation by company representatives, and evaluation by professors, based on the criteria presented in Table 3.

Table 3. Assessment Description

Type	Competencies to be developed	Assessment Criteria
Technical	Ability to identify and solve complex problems through the design of integrated product and service solutions, considering the requirements of multiple critical stakeholders	Quality of the proposed solution (System Map and Lean Canvas); Critical stakeholder demands considered
	Ability to collect and analyze relevant requirements and consider sustainability aspects in the integrated solution project, from the initial phases of the development process	Clarity and quality of prioritized and technical requirements; Relevance of prioritized processes (Product-Service Blueprint); Potential contribution to sustainability
Transversal	Ability to work as part of a team, encouraging effective communication of ideas and solutions with team members and external stakeholders involved in the project	Individual contribution to project development; Leadership and teamwork; Clarity and objectivity during the Pitch; Demonstration of mastery of the content

The self-assessment aims to identify students' perceptions of the PBL practice and highlight opportunities for course improvement. For this purpose, a questionnaire was developed, divided into two sections (I and II). In sections I and II, students rated each question on a scale from 0 to 10. Section I assessed the Project Development and RE competencies, including: i) Ability to design integrated, sustainable product-service solutions to address complex, real-world problems; ii) Leadership in group engagement and work organization; and iii) Ability to work as a team. Section II contained two open-ended questions regarding the overall evaluation of the course and student satisfaction with the PBL practice, where students could highlight positive and negative aspects and suggest improvements. No structured assessment instrument was proposed for partner companies based on RE competencies. However, representatives attending the final class to review the results provided feedback, expressing the impact of the academic activity on their organizations.

4. Results and Discussion

This section analyzes and discusses the results of implementing the PBL practice in the DSPSS course. Table 4 summarizes the challenges posed by each partner company and the solutions provided by students following the application of the R-PSS method to the projects developed during the eight editions of the course. During this period, 62 students engaged in the course and established collaborations with 13 companies. The developed prototypes integrated the prioritized requirements of diverse stakeholders, sustainability considerations, and the combination of product and service features within the PSS solution.

Table 4 - Company interaction projects

Semester	Company	Challenge/Problem
2021-2 (12 students)	Waste management company	Increase scalability without requiring additional physical space or workforce
2022-1 (9 students)	Startup for water level measurement solutions	Validate the business model among market segments
2022-2 (10 students)	Digital solutions startup for shared wardrobe compartments	A sustainable solution to improve the logistics of shared locker room services.
	Solution startup for connecting volunteers to research centers	Design a solution to scale the business of capturing and recruiting volunteers to participate in research.
	Industrial materials purchasing services company	Validate business model with potential customers
2023-1 (9 students)	Industrial materials purchasing services company	Adapt the previously designed solution to meet ESG criteria.
	Biodegradable packaging production startup	Validate the business model with potential customers from nurseries and small farmers.
	Regenerative agriculture solutions startup	Increase the scalability of the training and promotion solution for small producers.
2023-2 (9 students)	Ballet costume production company	Design a sustainable business model to produce ballet costumes to contribute to the circular economy.
	Startup of educational toys for special education	Increasing the scalability of the educational solution for various stakeholders
2024-1 (6 students)	Startup connecting clients and service providers for the LGTB community	Validate a sustainable business model
2024-2 (8 students)	Socio-environmental innovation project	Project for new sustainable solutions from plastic waste
	Sustainability School	Increase the scalability of immersive environmental education services through water resources

One of the prototypes developed during the course was *Bioativo* (https://giovanacosta1009.wixsite.com/bioativo). *Bioativo* is a startup specializing in biodegradable packaging, offering a sustainable solution for plant seedling cultivation. Using Brazilian technology, the company develops high-quality biodegradable films to reduce the environmental impact of microplastics on soil, plants, and the ecosystem. The startup faced the challenge of validating its business model with potential customers, such as nurseries and small farmers, by demonstrating the value and viability of its integrated solution. To support this effort, students developed a prototype website to showcase *Bioativo's* products, highlight the benefits of its sustainable technology, and facilitate connections with potential clients and partners.

The professors noted substantial advancement in technical and transversal RE competencies, particularly in teamwork, collaborative learning, logical thinking, and applying knowledge to real-world projects. Partner companies indicated satisfaction with the proposed solutions, particularly regarding their relevance and feasibility. Some representatives expressed positive surprise regarding the quality of the solutions provided within approximately three months. The partial deliverables submitted by the groups during the semester reflected significant commitment, proactivity, dedication, theoretical depth, and creativity, as assessed by the professors. That corresponds with students' self-assessment of their performance in the competencies developed by the course, as measured by an electronic questionnaire. The mean scores exceeded 9 (on a scale from 0 to 10), as illustrated in Figure 1. Consequently, addressing real-world problems demonstrated an effective approach to enhancing RE competencies.

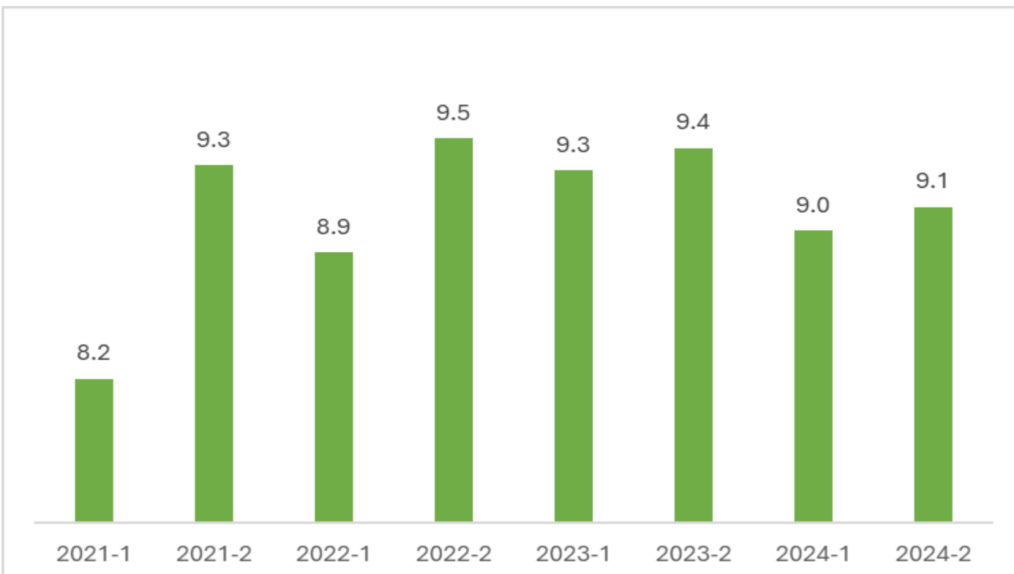

Figure 1. Average score in self-assessment on the development of RE competencies

Feedback from students regarding the course emphasized the importance of hands-on experience, facilitating the integration of theory and practice while fostering competencies in leadership and teamwork. The PBL practice received considerable acclaim, and the students acknowledged its positive impact on their learning (Monteiro et al. 2017; Pereira et al. 2017). The synergy between theory and practice and flexible scheduling for activities were positively received, along with the instructors' guidance (Karim et al. 2019).

The approach promoted significant engagement in business plan development, enhancing the relevance and applicability of learning to professional contexts (Jollands et al. 2012). Numerous students indicated that this dynamic enhanced their motivation and sense of responsibility, as they perceived a clear and relevant purpose in project development (Guo et al. 2020). Challenges were identified, including the intensive workload and difficulties in engaging certain partner companies (Dinis-Carvalho et al. 2017). Furthermore, recommendations for enhancement from the earlier editions of the course highlighted the necessity for more organized follow-up and more comprehensive written feedback—elements that have been progressively refined in each subsequent edition. Despite these challenges, the course received broad recognition as a valuable experience, aligned with market needs and pertinent to students' professional growth.

Students made strides in tackling complex problems by designing integrated product-service solutions. The projects, developed in collaboration with industry partners, closely reflected stakeholder expectations and successfully combined technical and transversal competencies (Holtkamp et al. 2015). Both parcial reports and final virtual prototypes demonstrated a well-organized approach to problem-solving, emphasizing the effectiveness of project-based learning in fostering these competencies (Jantunen et al. 2019). Students systematically identified and prioritized key technical (Correa and Danilevicz 2015) and sustainability-related requirements through regular interaction with companies. They applied structured frameworks, including Lean Canvas, Quality Function Deployment, and Product-Service Blueprint, to organize their requirement analysis and ensure sustainability aspects were embedded early in the process. The outcomes of their projects illustrated a clear dedication to sustainable design principles.

Company feedback and student self-assessments showed noticeable improvements in communication competencies, reasoning behind design choices, and teamwork efficiency. The collaborative nature of PBL encouraged active participation and smooth exchange of knowledge. High self-evaluation scores among students reinforced these observations, supporting research highlighting the role of PBL in enhancing transversal competencies. (Silveira et al. 2022). Students expressed greater independence, engagement in learning, and the ability to apply theoretical knowledge to practical scenarios. Responses in open-ended surveys emphasized motivation and enthusiasm as standout benefits, with many valuing the direct connection between coursework and real-world applications. These findings align with existing research on PBL's role in promoting deep learning and professional competency development (Thomas 2000; Guo et al. 2020. Industry partners provided encouraging feedback regarding the practicality and relevance of student-generated solutions, with some concepts undergoing refinement for potential real-world applications. Representatives from companies recognized the importance of academic collaboration in addressing contemporary business challenges, reaffirming the necessity of strong university-industry partnerships in preparing engineers for the workforce (Cheng and Yang 2019).

Despite the positive outcomes observed with the implementation of the PBL approach, certain challenges were encountered throughout its application. One of the main difficulties involved coordinating schedules to enable interactions between students and partner companies, given that a significant proportion of the students enrolled in the course are concurrently employed or undertaking internships. Additionally, some companies that initially committed to participating in the projects faced time constraints during the semester, which limited their ability to engage consistently with the students. To mitigate these issues, specific strategies were adopted in the project selection process. The course established a partnership with one of the university's incubators, and in collaboration with the incubator's management, selected startups that demonstrated genuine interest and availability to work alongside students in addressing their business challenges. Another recurring challenge concerned the complexity of the proposed problems. In certain instances, partner companies presented issues that exceeded the course's scope and feasibility. In such cases, faculty members were required to align expectations and redefine deliverables in accordance with the academic constraints of the course.

5. Conclusion

This study examined implementing a PBL practice in the DSPSS course, using real-world challenges proposed by partner companies. The method integrated theoretical knowledge with practical application through structured tools such as Lean Canvas, Quality Function Deployment, and Product-Service Blueprint, fostering essential technical and transversal competencies among students. The results demonstrated that PBL effectively bridges academia and industry, equipping students with problem-solving, sustainability, and communication competencies. The direct application of academic knowledge in real contexts provides students with valuable practical experience, facilitates learning, and prepares them for the job market. Collaboration with companies can generate innovative solutions to specific challenges, benefiting organizations with fresh insights and creative approaches. This interaction strengthens ties between academia and the productive sector, creating a mutually beneficial knowledge network.

Improvements in students' ability to identify and solve complex problems, analyze and integrate sustainability considerations into requirements, and communicate effectively within teams and with external stakeholders were also identified. Students have gained technical expertise and developed crucial transversal competencies necessary for modern engineering practice by engaging in real-world challenges proposed by partner companies.
The findings suggest that PBL enhances students' learning experiences by providing a structured yet flexible environment where theory is continuously applied to practical problems. Self-assessments and course evaluations indicate that students perceive a significant improvement in their competencies, while industry feedback confirms the feasibility and relevance of their proposed solutions. These insights emphasize the importance of active learning methodologies in preparing future engineers to address contemporary challenges, particularly in developing sustainable product-service systems.

Additionally, the study validated and improved the R-PSS model, initially published in 2020, demonstrating its applicability to various challenges and business models, including startups and well-established companies. The enhancement was achieved by incorporating new tools for: i) qualitative assessment of sustainability contributions (Silveira et al. 2022), ii) evaluation of solutions against circular business models, and iii) virtual prototyping of sustainable integrated solutions. Despite its success, the study also highlighted key challenges. One significant issue was aligning student project schedules with the availability of startup partners, whose working hours often extend beyond standard academic periods. Additionally, managing the intensive workload required for project execution—beyond formal class hours—proved demanding for students. These logistical constraints suggest a need for improved coordination strategies between academic institutions and industry partners.

Future research should explore ways to optimize PBL practice to better accommodate external stakeholder constraints better while maintaining educational effectiveness. Integrating hybrid learning models with asynchronous collaboration tools could help address scheduling conflicts. Expanding the scope of industry partnerships, particularly in sustainability-driven projects, may enhance the learning experience and further align engineering education with emerging market demands. This study contributes to the literature on PBL in engineering education, reaffirming its role in bridging the gap between academic learning and industry demands. By continuously adapting and improving pedagogical strategies, higher education institutions contribute to equipping industrial engineering graduates with the necessary competencies to function in the increasingly complex and sustainability-oriented professional landscape.

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