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Teaching Strategies in Industrial Engineering Programs in Brazil: Benchmarking in North American Universities

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Engineering education in developed countries is seen as a benchmark for all others. Its teaching strategies, combined with assessing knowledge and the infrastructure of modern laboratories and classrooms, allow students to develop their skills and prepare themselves professionally for the job market. At the same time, engineering education is not valued in Brazil. Its teaching methodologies are traditional and directed towards a final concept. With this, essential skills for the job market are partially developed, such as teamwork, problem-solving, and critical thinking. Thus, as similar strategies to those that companies do, a benchmarking to understand how this process takes place. This benchmarking is essential for directing engineering education based on best practices already adopted by other universities. In this context, the present study investigates the possibility of inserting North American teaching strategies in Brazilian universities focusing on engineering. As methodological procedures, unstructured interviews were used in a focus group with six American universities. In these groups, professionals related to engineering education were invited: Professors, Members of teaching and learning centers, and administrative support and support technicians. In addition to the interviews, direct observations about the infrastructure and the procedures adopted in their teaching were conducted to analyze their complexity. As a result, we highlight the development of strategic partnerships with local industries in which alumni are the main means of engaging these partnerships, the development of unique competency management that involves the entire university, and the need for innovation in the education environment in engineering so that the university can be increasingly inserted in the context of open innovation with a focus on attracting new students, economic and geographic growth and local social impact with a focus on community development.

Keywords: International Benchmarking; Active Learning; Industrial Engineering.

1. Introduction

Engineering education in developed countries is a benchmark for all others [1]. In these universities, different ways of teaching students are used to make learning more realistic and attractive. North American universities, for example, are excellent references in investments in the education of their engineering courses, as well as in modern teaching and adequate infrastructure [2].

Considered by different authors as one of the best ways for students to acquire complete and realistic knowledge, active learning is another way of teaching. This approach is student-centered, ensuring that professors are professionals who guide students in this process [3], [4]. The involvement of the whole class increases from active learning strategies, making it possible to develop an opportunity to reflect on learning in a set of solutions to real problems [5].

The different active learning strategies also guarantee the development of professional skills that students must acquire throughout their training. Problem-solving, communication, ethics, and critical and systemic thinking are examples of skills that allow the formation of a professional more suited to the job market [4], [6], [7]. In addition, classes based on these different approaches ensure a more significant relationship with the labor market and current problems, making the study more attractive and making the student visualize his actions in a professional future [8].

However, this only occurs in some universities with engineering courses in developing countries, such as Brazil [5], [9]. In these environments, teaching is traditional, using an expository class with a blackboard and slide presentation [10]. Different authors approach this problem as a deficiency in education, where the knowledge necessary for an engineer is compromised. Allied with this fact, the evaluations of these students are also traditional, based on tests and descriptive evaluations. In Brazil, this scenario is prevalent because the resources designated to public universities for investments and improvements in teaching and learning are limited.

From traditional teaching methodologies, the development of professional skills can also be compromised [11]. The student needs to work in a team and work with structured problems in the literature [12]. Other consequences observed in the literature are the unpreparedness of the future professional, school dropout [13], and lack of student commitment and cooperation [14].

There are different factors to observe when replacing traditional methodologies with active learning strategies. A professor support team is essential, allowing academic support and company relationships to bring real and unstructured problems [15], [16]. Still, the infrastructure must provide subsidies for group activity, allowing interaction between students and, simultaneously, the possibility of explaining content by professors [9]. The number of active learning classes and activities increases compared to traditional learning, consequently increasing the professors' workload.

Even so, the different benefits of active learning are proven in the literature. These advantages, for example, are the improvement in teaching, attractiveness, and the development and training of professionals that the job market expects [17], [18], [19]. This benefit is even more significant regarding courses such as Industrial Engineering since the

concepts presented in this graduation are complex and managerial. Bringing the problems and case studies into the classroom prepares students more realistically for the professional environment. It is possible in all areas of production engineering, such as production planning and control, logistics, product development, and work safety [20].

In their studies, Andersson et al. [21] concluded that Industrial Engineering students feel more motivated when taking classes with active strategies. Lima et al. [22] show that using active learning in this engineering specialty reduces the gap between the required skills and the skills students acquire. Alves et al. [23] also present positive results based on the critical reflection of industrial engineering faculty who work with active learning.

Therefore, to get to know a panorama of excellence in teaching industrial engineering, strategies seen in the labor market can also be approached in universities. Benchmarking, for example, allows comparisons between institutions to increase productivity and accelerate innovations in the productive environment [24]. In the case of universities, it is possible to find out what educational institutions are implementing and researching to increase the area's effectiveness, directing engineering teaching based on the best practices adopted by other universities and ensuring an improvement in the student's training process [25].

Therefore, this study is justified by the need to transform the education of production engineering undergraduate programs at Brazilian universities. It is possible to bring about improvements when we know the other leading universities and their methodologies that suit the teaching of these future professionals, making it more accurate and attractive. With this, universities benefit from contributing to their modernization, both for their professionals and their infrastructure. As for the literature, this study can be justified by raising possible difficulties in inserting different teaching methodologies, making researchers and universities find solutions to correct and circumvent these problems.

This work investigated the possibility of inserting North American teaching strategies in industrial engineering undergraduate programs at Brazilian universities. For this, non-structured interviews and direct observations were carried out in different American universities, raising the main characteristics of teaching and its other proposals. This research noticed various active learning strategies used in U.S. universities, making the student have contact with companies from the beginning of their training. However, several factors need to be modified in Brazil to do this insertion, such as creating a nucleus to capture company problems, investment in faculty training, and improving the infrastructure of classrooms and research laboratories.

This research is associated with the Modernization of Undergraduate Education Program (PMG), supported by FULBRIGHT, CAPES, and U.S. Embassy in Brazil [26]. Industrial engineering at the Federal University of Rio Grande do Sul is one of the participating courses. This public university has participated in this project since 2019, with professors on missions to partner with North American institutions [26], [27].

2. Methodology

To investigate whether the teaching strategies present in North American universities can be used in Brazilian universities, an investigation of different necessary factors was carried out in loco. For this, we used a qualitative and descriptive study to highlight the main points used by these teaching methodologies from the perception of education specialists.

The descriptive study aims to deepen and improve knowledge on topics related to the insertion and use of active strategies in teaching production engineering [28]. The study can be characterized as qualitative because, with the help of textual analysis, it seeks to analyze the context of what is happening, its main reason, and its consequences [29]. Qualitative investigations seek to describe the phenomenon in depth, explaining the results from the insertion of the context [30].

For this collection, the study sample contemplated six universities visited in 2022. These universities are located in New York City, Boston, and New Haven and are important in engineering education. In addition, they have great worldwide relevance for their research. These universities are internationally recognized for their active pedagogical practices and their research in engineering education. Using different strategies, universities guarantee students dynamic learning experiences, bringing business problems closer to the classroom and proposing solutions based on theory and practice.

The factors that allow the insertion of active strategies in engineering education were raised in two ways: from non-structured interviews in a focus group and direct observations. In unstructured interviews, the interviewer talks about previously established topics but with minimal restrictions on the questions asked during the process [31]. Follow-up questions are encouraged, increasing the discussion about issues related to the theme. These interviews were conducted in focus groups, as they are appropriate when expected a dynamic between participants, allowing for more excellent discussion and detailed responses [32], [33].

Based on PMG's objectives, the interview investigated issues related to active university teaching strategies [26]. For this, discussions were raised on:

1. The teaching methodologies used.
2. How is done the industry-university collaboration.
3. The limitations found in this active process.
4. The infrastructure and knowledge needed for the insertion of these strategies.

As the method allows, the interviewers asked questions related to the four points to encourage and deepen the discussion, such as the student's perception of the different strategies, the added workload for professors, and the technical and administrative support received.

A focus group was formed at each analyzed university to investigate these questions. These groups contained faculty from undergraduate engineering programs, members of teaching and learning centers, administrative support, technical support, and students. We sought to bring different actors involved to know their perceptions and encourage discussion about the advantages and disadvantages.

In addition to the interviews, direct observations were made in the infrastructure of the universities. Infrastructure is essential in engineering education because professors can design their activities from it. Thus, understanding how it was designed and the way it is used is significant for the study to know if similar infrastructures are needed in other universities. For this, professors and technical support professionals were interviewed and, at the same time, showed the university's infrastructure.

Each visit, which included the interview and observation, took an average of two hours. With the participants' permission, the interviews were recorded in their entirety. All these were transcribed for further analysis. The results were analyzed based on a content analysis, which guarantees understanding how a situation occurs based on theoretical structures, analyzing significant texts, and dividing them into key discussion categories [34], [35]. The university initially divided these categories, presenting their main active teaching strategies. The discussion was carried out critically on the possibility of inserting the active processes observed in industrial engineering courses at Brazilian universities.

3. Results

The results show the main practices highlighted by the six universities visited and analyzed.

University 1

Competency-based teaching and curriculum
Curriculum and competences are related since the university model is competency-based teaching. Nine university-wide competencies are used, based on the Accreditation Board for Engineering and Technology (ABET). And curricula are flexible and built based on skills. Thus, engineering students can create their curriculum and develop their competences and skills. This is important in Industrial Engineering and Operations management context because there are several areas of study, such as knowledge management, ergonomics, and digital transformation. Hence, engineering students can choose the path they will follow based on the competences and courses available. In addition, access to disciplines related to competences is facilitated through the website. Therefore, engineering students can access information and analyze the subjects most suitable for their development.

Co-ops
The analyzed university has a Cooperative Education (Co-op) program. This program supports the development of soft skills in engineering students. The main goal of the Co-op program is to bring students closer to industry. For Industrial Engineering students, this is important because industries are their object of analysis. Immersed in the industrial environment, they can better understand industrial concepts. Therefore, students can also better understand the job market and analyze if they will follow one career or industry based on their experience during the undergraduate course. Because of it, this program has a high level of engagement since students can choose their professional path. In Brazil, there are similar programs called internship, research assistant, and exchange. However, these programs need a dedicated team for students. Generally, students need to look for internships at companies or internship agencies, talk to professors with research grants, and look for exchange notices or exchange agencies or do it independently. Sometimes industrial engineering students need help finding an internship in industries because they need an industrial contact. Then, they depend on professors and their connections and must explore different contexts. In this way, unfortunately, an environment that strengthens the university's relationship with industry is not created. Therefore, there is a need to develop a program like a Co-op for industrial engineering and operations management.

University 2

Competency-based teaching and multidisciplinary

The university focuses on competency-based teaching. The competences cross all the engineering courses offered by the institution. However, as the institution is small, engineering students are encouraged to take courses at other universities to obtain more interdisciplinary knowledge, such as biology and entrepreneurship, instead of only focusing on traditional engineering courses. However, industrial engineering students study different engineering courses, they are not encouraged to seek specific knowledge outside the engineering area. Thus, in addition to engineering students developing competences and knowledge in their main course, industrial engineering students can expand their knowledge in other areas. This is very important for the Brazilian job market and Industrial engineering because students work in different places, like financial, renewable energy, and pharmaceuticals.

Infrastructure to promote hands-on learning
The university is built to enhance the hands-on learning process. For example, the library is not only for books and studying but also equipped with cameras, games, sewing machines, and spaces that engineering students can use to build their prototypes and learn more about how they can create a new product with their own hands. This environment is essential for engineering students to learn how to organize the building process and the steps they must follow to build a teddy bear. Besides that, other hands-on spaces are offered to students. These spaces are used during their courses, faculty research activities, student club activities, and individual student projects. Therefore, engineering students can find other hands-on areas to conduct their projects if the library is unavailable. Some of these spaces are for specific materials such as metals, wood, and plastic, facilitating learning and making equipment. Even in the building corridors of the university, areas can be found for students to have hands-on activities. This promotes increased student engagement in this type of activity and facilitates the development of skills related to innovation and creativity. Hands-on learning is very important for industrial engineering students because several courses are mandatory to create a new idea. If industrial engineering students could prototype their ideas, they can refine products better. Therefore, there is a need to create environments that develop hands-on work so engineering students can develop new skills and competences.

University 3

Teaching and Learning Center
The teaching and learning centers are essential for faculty, students, and the entire academic community to have someone to help add modern practices to classes, learn to deal with new teaching and digital technologies and new teaching methodologies, modernize the curriculum and much more. These centers offer workshops and consultancies to facilitate the development of teaching and learning across the academic community. For instance, the teaching and learning center supports the development of new courses, explaining how to create a course, explaining how to create a course, and what approaches can be used. Also, the center has a workshop about how to create a course program and how to create a more learning-focused program. In addition, the center has workshops about the inclusive classroom, covering how to create an inclusive classroom: how to develop practices that include academic belonging, and how to guide discussions about this sensitive topic. In Brazil, these inclusive programs are necessary because public universities work with a quotes program, and several issues should be included in industrial engineering courses. This is because some students need help to afford to visit some industries because they are from low-income families. Then, professors should rethink how they structure classes to integrate these students.

Additionally, it is important to point out that, during the pandemic, to improve the teaching and learning process, the demands of the laboratory increased due to the need for change in various aspects of teaching and learning. This enabled a greater engagement of the academic community with the Teaching and Learning Center, enabling other departments to understand the relevance of the center. In addition to providing consultancy, advice, and holding workshops, the center uses scientific methodology to prove that the methods work. In this way, in addition to supporting the university community, they generate scientific knowledge. This developed knowledge is essential to convey confidence. For instance, research only with industrial engineering and operations management students could be conducted by this center to generate insights that can improve the teaching and learning for this course.

Furthermore, the basic engineering disciplines (calculus, chemistry, and physics) seek the center to promote new teaching methods and introduce group work to solve complex problems. For example, concerning class, the use of clickers in base engineering courses such as statistical probability, chemistry, and physics was mentioned by professors. In this class style, students are invited to reflect on early insights and undertake a larger analysis with a focus on developing critical analysis. As industrial engineering and operations management, students take these classes, and this will direct impact their learning. Finally, teaching and learning centers must be created in universities to promote technical methodologies and facilitate the dissemination of knowledge in the academic community, in addition to impacting student learning.

Tracks and certificates
It is important to point out that students have the same basic training that is differentiated by the tracks and certifications they follow. These tracks and certifications are essential for students to develop market-specific skills. The focus is to bring students closer to the job market and promote networking with more advanced students. The tracks aim to prepare students for the market, strengthening their relationships. Tracks are generally an integrated program of courses and activities aimed at exposing students to practices, grounding students in the principles of theory and applying theory to real problems, providing students with an overview of career opportunities and creating a cohort of students and alumni in specific careers. In addition to the tracks, this university offers academic certificates. Students can pursue specialized certificates in different areas, such as machine learning, pharmaceuticals, sustainability, and innovation. Certificates must be earned with a degree; they are not stand-alone, non-degree programs. Certificates have different specific objectives, and depending on the area, they will be focused on a particular industry, concept, technology, and innovation in general. Therefore, the tracks and certificates are used to further prepare students for the job market, developing specific knowledge necessary for professional development. Regarding industrial engineering and operations management, tracks and certificates are relevant because students can work in several areas. These tracks and certificates show in-depth knowledge about a specific topic, like digital transformation, ergonomics, and quality.

University 4

Infrastructure to promote hands-on learning
The university has a center that promotes hands-on learning and activities. In this center, students can build whatever they want for the subjects and the various university clubs. This hands-on learning environment is very important for developing teamwork and critical thinking. In addition, graduate students are assistants and give some practical classes to

undergraduates. These graduate student professors manage to develop other skills, such as communication, and provide technical engineering classes to support the projects that are relevant for industrial engineering students. So, when students learn with this graduate student, they apply the knowledge to their project. Moreover, the center has several machines, tools, and materials for students to develop prototypes. The resources are fantastic for creativity and innovation in the academic environment. Using resources, high-level engineering projects are being developed more easily, and students can reach foreign markets. The hands-on center encourages students to develop their technical and soft skills as it works with applied projects, bringing them closer to the job market. Finally, creating a hands-on learning environment appeared as a highlight for engineering study because it promoted many student learning benefits. Regarding industrial engineering students, a hands-on center could enable that prototype to be developed faster, and all group members visualize what is being discussed because sometimes, when there is only a 3D model is difficult to discuss the following steps. However, industrial engineering students can think about production systems, packaging, and supply chain when there is a tangible object. With the object, it is easy to think about all the steps to build it.

Industry and Entrepreneurship
The university focuses on strengthening the relationship with alumni and industry, mainly to develop the work applied at the center. For example, as the region has some museums, several lighting and temperature projects are being developed based on Arduino, sensors, programming, and Industry 4.0 technologies. This shows that the approach with the industry brings benefits of using state-of-the-art technologies to solve practical problems. That is, students, in addition to receiving knowledge, promote industry innovation with solutions that are created by them and guided by professors. This shows the importance of developing a strong and healthy relationship with the industry. For instance, considering industrial engineering courses, if students follow a digital transformation track or certificate, they could build a roadmap to Industry 4.0 for some industries and museums to apply their knowledge in real cases rather than only doing case studies.

Furthermore, entrepreneurship is encouraged by the teaching and learning center and the university. The university strengthened its relationship with the health area. Engineering students developed several projects in this area and created startups that are operating internationally, producing equipment that helps in the execution and counting of physical exercises. The prototype of the equipment was manufactured in the center, and today its production is carried out in China, showing the great entrepreneurial potential of students with access to the right resources. For instance, industrial engineering courses are also related to the health area. Some studies are used to improve layouts of the emergency room by analyzing knowledge management based on social networks. In addition, studies are conducted using operational research to do the sequencing of operating rooms. These are only two examples of several that industrial engineering students could work. In this way, the relationship with industry and promoting entrepreneurial activities are two incredible mechanisms for developing an entrepreneurial engineer.

University 5

Project-based learning
The university focuses on final work (capstone) with the practical application of engineering concepts. Usually, students look for a mentor professor with a list of demands and projects they prioritize. Based on this list and some discussions between the professor and student,

some potential work themes are discussed. At this university, solutions are carried out more academically with laboratory tests rather than industry tests. The focus is to develop knowledge in the student in the form of a project. That is, the student will work on final projects of the engineering course or operations management with the advisor, professor, and graduate students. At that time, the engineering student, in addition to developing technical capacity, will develop other important skills and competences, such as communication and teamwork. In this way, even if the focus is not on the industry, the focus remains on students developing soft skills. The professor exemplified operations management research and the simulation of the use of resources in assembly lines and transportation modes to reduce costs in supply chains. Finally, these projects can be used in engineering college, as many professors have lists of projects they want to pursue and well-defined lines of research. However, in addition to approaching the academy, it is suggested to approach the industry.

Developing competences

The university has a strong focus on developing global leaders. For this, the focus on skills development takes place on different fronts. First, written competence is developed through a course. The professor explained that students "think" they know how to write, and the discipline helps all engineering students to write simple, clear, and cohesive writing for everyone to understand. Second, students develop oral competence in job presentations during their engineering degree. For example, chemical engineering students were the ones who had this competence more developed since they presented many works during the course, and this allowed them to create this competence more. Third, leadership development is when students need to lead their final project. That is, students are required to keep the objective in mind and manage the team and resources. To do so, they need to develop project management and leadership skills. All the competences cited are essential for industrial engineering students and leaders. Therefore, the way that was approached in this university could be replicated in industrial engineering courses. Finally, all these actions are to build confidence in engineering students so that they can solve engineering problems in the external environment.

University 6

Teaching and Learning Center

The teaching and learning center is essential for this university, as it provides the community with workshops, training, and personalized consultations on teaching-learning processes and all related issues. The center helps develop classes that promote teamwork and that students who have already taken the course can be tutors of the students who are taking it. So all students can build teamwork and communication skills. For example, the chemistry class for engineering students (industrial engineering students take this class), is divided into three moments. In the first part, "I do/we do", the professor solves the exercises with the students, allowing doubts to be questioned. The second moment, "We do", consists of solving problems in small groups of students. For this, the professor and other engineering student assistants help with doubts and discussions between the learning groups. This allows the development of teamwork and student interaction, as the groups vary every week. Finally, the third part of the class is defined as "You do", where students have different exercises to solve and submit on the university platforms after class. This pedagogical strategy allows engineering students to learn alongside the professor, practice in small groups, and test their knowledge individually. In fact, this type of class could be replicated in all basic engineering classes, such as physics, calculus, and statistics which will impact all engineering students. In

conclusion, the center helps to introduce more modern pedagogical practices so that students learn more easily as done with a chemistry class.

Furthermore, the center promotes several workshops for the academic community. These workshops cover subjects ranging from the first contact with students to the methodology used in the classroom. For instance, the workshop "Strategies for an inclusive class". For this workshop, four main sections were discussed:

1. Getting to know your students, where it was discussed how to learn to say the students' names and how to use techniques to break the initial ice in the classroom.
2. Diversifying the course content, where it was debated about posing scenarios and problems covering different socioeconomic statuses, ages and religions, and reflecting on the curriculum to determine the main gaps.
3. Developing class norms, where there was talk of adding student inclusion statements and co-creating criteria and guides for students and professors.
4. Incorporating flexibility into course design, building flexibility policies for deliveries in different periods, and combining the flexibility of participation policies and the format of the classes.

Therefore, these workshops are very interesting to be replicated in engineering courses. Professors can learn a lot from the workshop and even promote better integration of students with the class.

Infrastructure

The university's infrastructure was developed to promote interaction among students. The university's main strengths are creating different classrooms encouraging teamwork and communication. The university's classrooms have a modern design and the possibility of adaptation, always seeking student interaction and their best comfort. In auditorium-style classrooms, projectors, blackboards and computers were observed for professor use. The mobility of some auditorium chairs can rotate 360°. This allows group activities to be done during classes, not being a fixed structure for just traditional engineering classes in the auditorium. That is, even in courses with many students, it is possible to conduct work and group discussions. Active Learning Classrooms are designed for collaborative and group-based activities. These are arranged in nine groups to serve up to 10 students in each group. These islands are equipped with television, whiteboard space, different cables and connectors and microphones. Each one interacts with the professor's island, located in the center of the room. This island has televisions in its surroundings so that the whole class can visualize what is projected and have space to serve the students and adapt all the furniture. Engineering students are invited to solve programming, calculus, physics, and chemistry exercises in these classes in groups. In conclusion, the university's infrastructure allows the elaboration of different courses and pedagogical approaches in engineering classes. Therefore, in Brazil, similar structures can be built that facilitate using more modern pedagogical approaches.

Based on the results, Table 1 was built that shows some important aspects of the analyzed strategies.

Table 1 - Summary of results

Main strategies	Where they are implemented	Implementation period	Challenges to implement
Develop a competency-based curriculum	Across the university	Long-term	Change the mindset to competences; Mapping and developing skills needed for engineering; Collect the assessment for use in the ongoing curriculum redesign process.
Create strong programs with industry	University and industry interaction; Creation of a center for this interaction	Long-term	The very great cultural separation of industry and university in Brazil; Difficulty finding jobs in the post-Covid industrial environment;
Students taking subjects from other courses	Across the university	Long-term	In public universities in Brazil, the problem is the number of vacancies available in the disciplines; The limited supply of disciplines in other courses; Displacement difficulties between university campuses;
Development of an infrastructure for learning	Across the university	Long-term	It would need to create some very different structures for students to have practical environments of various disciplines. For example, industrial engineering needs to create environments of quality, digital transformation, ergonomics, and economic engineering. In addition, for instance, universities would need to create chemistry, physics, mathematics, calculus and statistics in engineering. Still, more funding for creating different rooms is a challenge.
Creation of hands-on spaces	Engineering programs	Medium-term	In public universities, find financial and budgetary resources. Find spaces that can be used. Include in engineering disciplines moments to use space.
Development of entrepreneurial engineers	University and industry interaction	Medium-term	Difficulty finding contacts with engineering entrepreneurs and industrial engineering entrepreneurs
Development of Teaching and Learning Center	Education programs	Medium-term	Show the importance of the center; Publicize the activities of the center
Creation of tracks and certifications	Each college	Short-term	Engaging students to initiate additional certifications, Help students choose certifications; Curriculum changes to support certification.
Development of activities with applied projects	Each college	Short-term	Find places willing to receive students (industries, private sector); Being in an innovative environment; Make the teaching staff aware of adopting this teaching strategy.

4. Discussion and Conclusion

Based on our results, we could achieve our research goal by analyzing six North American Universities. In sum, our findings highlight four important benchmarking aspects to be implemented in engineering colleges: (i) developing a competence-based learning model to structure all courses, majors, and minors (ii) creating a robust infrastructure and hands-on space; (iii) developing of teaching and learning center to support academic community; (iv) developing a closer interaction with industry.

Concerning competency-based learning, competence can support students to reach the job market requirements skills rather than only technical skills. For example, engineering colleges in Brazil are known for developing hard skills by doing traditional engineering classes. However, this type of class is content-based instead of competence-based. Because of this pedagogical structure and curriculum, some junior engineers still need to develop their soft skills as required by the job market. Considering this scenario, the best teaching and learning strategy is creating a competence-based curriculum to develop soft skills in engineering students. Therefore, Brazilian universities should invest in creating a competence-based curriculum for engineering colleges. ABET has already produced some competencies in the US that North Americans Institutions should follow. These competencies could be an input to develop competence-based learning in industrial engineering colleges in Brazil. For example, in the case of Brazilian public universities, some institutions have already changed industrial engineering courses. However, competences are only widespread in some industrial engineering programs.

Regarding infrastructure and hands-on spaces, infrastructure is a key aspect of teaching and learning since the environment should support some important teaching strategies to develop specific competencies. In this sense, North American Universities have built an infrastructure that promotes teamwork, presentations, leadership, and communication. Because of that, some engineering students are becoming global leaders and starting their own companies. This entrepreneurship is a consequence of how the robust infrastructure supported their professional development because they have access to basic items that enable the development of prototypes. These prototypes were refined until the market solution was ready to be tested. Additionally, these engineering students have spaces to discuss their prototypes with their colleges, so they receive ideas and suggestions from several points of view, including researchers, professors, and the academic community. However, even though most universities have shown a technological infrastructure, it can also be simple. For example, some big tables that support teamwork are the beginning of the competence-based classroom. Therefore, Brazilian industrial engineering colleges could invest in new classrooms to support this new competency-based environment. Later, they can invest in adding new technologies. For example, in Brazil, many universities are public, and resources are limited. Then, investment in infrastructure is difficult. Consequently, the need to gradually organize the change of classroom infrastructure and the creation of more integrative environments that favor learning.

Furthermore, the hands-on spaces have been highlighted during the visits. These spaces offer machines, tools, equipment, and materials that engineering students can use to prototype their products. These hands-on spaces provide different benefits. For instance, engineering students can learn how to use some machines and technologies (i.e., Arduino and 3D printers); engineering students can learn from their failures; hands-on spaces can provide the opportunity to innovate and integrate with different students. In addition, as North American

Universities created these spaces in libraries and corridors, the use of empty spaces is an advantage in creating hands-on spaces. Hence, industrial engineering programs and Brazilian universities should invest in creating tiny hands-on spaces that engineering students could use. For instance, 3D printers could be put in corridors for engineering students to print their models and sewing machines. For example, in some Brazilian industrial engineering colleges, public resources are being used for the development of digital laboratories. Some knowledge of digital transformation and Industry 4.0 can be tested in these laboratories. In these places, industrial engineering students will be able to see in practice the concepts of vertical integration, horizontal integration, and traceability using digital technologies. In addition to being used by students of industrial engineering, testbeds can be used by computer engineering and mechanical engineering students, among others. This creates an enabling environment for competence development.

Developing Teaching and Learning Centers could lead professors, students, and academic professionals to an advanced level of teaching and learning. These centers are the key to changing the engineering colleges in Brazil because they concentrate on one place of knowledge about how teaching and learning should be and researching new teaching and learning opportunities. Based on that, Teaching and Learning Centers can support the transition and add new pedagogical strategies by providing all academic communities with workshops, classes, and consultants. Instead of each engineering college having a teaching and learning specialist, Teaching and Learning Centers concentrate and disseminate all this knowledge. For instance, the center could refine the Industrial Engineering curriculum by benchmarking with different Teaching and Learning Centers about the engineering curriculum. Indeed, if Chemical Engineering orders the same assignment, the center could use the newest Industrial Engineering curriculum to develop a new curriculum for Chemical Engineering. This enables the engineering curriculum to be impacted because it can generate a cascading effect, modernizing all engineering courses. Therefore, under these circumstances, the impact of Teaching and Learning Centers is huge, and Brazilian universities should create their Teaching and Learning centers. Unfortunately, there are no specialists in adduction and learning in each Brazil unit and Industrial Engineering unit. The area of knowledge is limited to education, so it is difficult to implement new learning systems in engineering, including industrial engineering.

Teaching industrial engineering poses significant challenges related to professor engagement, motivation, and skills to modernize the course. Adapting universities to new pedagogical practices, such as active learning and skills-based assessments, also requires adequate incentives, resources, and infrastructure. To address these challenges, it is essential to provide professors with professional development opportunities and support to integrate innovative teaching methods effectively. Universities must also invest in updated technology and provide access to relevant resources to enable students to develop the skills necessary to succeed in the field of industrial engineering. By addressing these challenges, we can ensure that future industrial engineers receive the education and training they need to thrive in their careers.

As the job market becomes increasingly globalized and interconnected, it is essential for industrial engineering students to develop soft skills to enhance their professional development. While cultural influences may vary from region to region, transversal skills are necessary for the comprehensive development of industrial engineering professionals. These skills include effective communication, teamwork, leadership, problem-solving, and critical thinking. Industrial engineering programs must prioritize the integration of these skills into

their curriculum and provide students with opportunities to practice and refine them. By doing so, we can ensure that future industrial engineers possess the essential soft skills necessary to excel in the global job market and adapt to the changing demands of the industry.

As the last point to discuss, the development of a closer interaction between universities and industry (including startups) is a theme that is debated in the literature [36], [37], [38]. Based on the industry perspective, this interaction can lead to new revenues and business models because universities offer innovations. However, considering the universities' point of view, this cooperation with the private sector can better prepare engineering students for the job market. For example, when industrial engineering students learn something (i.e. game theory, institutional theory) in class and can apply this knowledge in the real world, they will understand easily because they have practical experience, as well as done in physics and chemistry laboratories. This type of interaction can lead engineering students to a different knowledge level in which they are the main actor in their knowledge development and can share their new knowledge with the academic community. In this sense, the knowledge sharing between industry, universities, society, and engineering students is enhanced.

Additionally, this practical and tacit knowledge is developed by this interaction. Because of that, Brazilian universities should invest in creating a way to be closer to industry by developing a strong relationship and network with alumni, for example, since the impact in developing new engineers is huge. By doing so, Brazilian universities will be able to show how engineering students could apply their knowledge in a company and show them that they will face some challenges during their career that their soft skills and technical knowledge will bypass. For example, in the case of industrial engineering, the difficulty in finding internships in the industry is a growing challenge because, during the pandemic, many industries closed, which reduced the offer of vacancies. This led to an increase in the competitiveness of places in the industry, and universities that have a closer relationship with the industry get the best sites. Therefore, the lack of a relationship between university and industry changes the area of activity of industrial engineers, who will work in the financial, services, and energy areas, for example.

In the Engineering Modernization Program, only some engineering undergraduate courses participate. Industrial Engineering at UFRGS, referred to at the beginning of this work, is the only undergraduate course in this specialization participating in this project. This benchmarking encourages other industrial engineering and engineering courses to modernize their teaching and infrastructure. Thus, this project is highly influential to engineering courses in Brazil by showing the data found from the relevance and impact of the program and its improvements in Industrial engineering at UFRGS.

Limitations and future research

Based on that, industrial engineering and operations management programs should invest in different ways to improve the development of engineering students. Several benchmarking strategies could be used to enhance engineering students' teaching and learning environment and experience. However, even though this paper has addressed understanding North American benchmarking strategies focusing on industrial engineering and operations management, the article shows that these strategies should be done but not how Brazilian universities could implement them in their engineering colleges. For instance, future studies could understand in-depth how universities create and improve their Teaching and Learning

Centers and create a framework for implementing them. In addition, future studies should address the necessity of creating Teaching and Learning strategies in their engineering programs to improve teaching and learning. Besides analyzing North American universities, Brazilian universities should also explore and visit European universities to understand their teaching and learning practices. Based on the analysis from foreign universities, Brazilian universities will have a wide perspective of how they could address some teaching and learning problems in the industrial engineering and operations management context. Therefore, future studies could include European Universities in the scope of analysis.

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References

1. D. T. Rover, "Engineering Education in a Global Context", *Journal of Engineering Education,* vol. 97 (1), pp. 105–108, 2008. https://doi.org/10.1002/j.2168-9830.2008.tb00958.x.
2. 2. A. L. Pawley, "Learning from small numbers: Studying ruling relations that gender and race the structure of U.S. engineering education", *Journal of Engineering Education,* vol. 108 (1), pp. 13–31, 2019. https://doi.org/10.1002/jee.20247.
3. 3. G. L. Tortorella, R. Miorando, D. Fettermann and D. T. Mendoza, "An empirical investigation on learning and teaching lean manufacturing", *Education + Training* vol. 62 (3), pp. 339-354, 2020. https://doi.org/10.1108/ET-11-2018-0232.
4. 4. B. Preeti, A. Ashish and G. Shriran, *"*Problem Based Learning (PBL) - An Effective Approach to Improve Learning Outcomes in Medical Teaching"*, Journal of Clinical and Diagnostic Research* vol. 7 (12), pp. 2896-2897, 2013. https://doi.org/10.7860/JCDR/2013/7339.3787.
5. H. Nguyen, L. Wu, C. Fischer, G. Washington and M. Warschauer, "Increasing success in college: Examining the impact of a project-based introductory engineering course", *Journal of Engineering Education* **[**Online], pp. 1-18, 2020. https://doi.org/10.1002/jee.20319.
6. P. Fernández and M. Ceacero-Moreno, "Study of the Training of Environmentalists through Gamification as a University Course", *Sustainability* vol. 13 (4), 2021. http://doi.org/10.3390/su13042323.
7. A. Lanzotti, A. Vanacore, A. Tarallo, D. Nathan-Roberts, D. Coccorese, V. Minopoli, F. Carbone, R. d'Angelo, C. Grasso, G. Di Gironimo and S. Papa, "Interactive Tools for Safety 4.0: Virtual Ergonomics and Serious Games in Real Working Contexts". *Ergonomics* vol. 63 (3), pp. 324-333, 2019. https://doi.org/10.1080/00140139.2019.1683603.
8. C. K. Lo and K. F. Hew, "The impact of flipped classrooms on student achievement in engineering education: A meta-analysis of 10 years of research", *Journal of Engineering Education* vol. 108 (4), pp. 523-546, 2019. https://doi.org/10.1002/jee.20293.
9. 9. A. Ahmed and K. Sayed. "Development of competency-based training system in Assiut- ITEC: A case study". *The Journal of Competency Based Education* vol. 5 (3), pp. 1-12, 2020. http://doi.org/10.1002/cbe2.1217.
10. B. Astolfi, D. Costa, C. Campese and J. M. Costa, "Project-based learning: a new way to teach ergonomics", in *Proceedings of 14th International Design Conference,* pp. 2037-2048, 2016.

11. M. Cruz, G. Saunders-Smits and P. Groen, “Evaluation of competency methods in engineering education: a systematic review”, *European Journal of Engineering Education*, vol. 45 (5), pp. 729-757, 2020.
12. E. Dringenberg and S. Y. Purzer, “Experiences of first-year engineering students working on ill-structured problems in teams”, *Journal of Engineering Education* vol. 107 (3), pp. 442-467, 2018. https://doi.org/10.1002/jee.20220.
13. F. Marbouti, A. Shafaat, J. Ulas and H. Diefes-Dux, “Relationship Between Time of Class and Student Grades in an Active Learning Course”, *Journal of Engineering Education* vol. 107 (3), pp. 468-490, 2018.
14. M. Borrego, J. Karlin, L. D. McNair and K. Beddoes, “Team Effectiveness Theory from Industrial and Organizational Psychology Applied to Engineering Student Project Teams: A Research Review”, *Journal of Engineering Education* vol. 102 (4), pp. 472-512, 2013. https://doi.org/10.1002/jee.20023.
15. R. Belwal, S. Belwal, A. Sufian and A. Badi, “Project-based learning (PBL): outcomes of students' engagement in an external consultancy project in Oman”, *Education + Training* vol. 63 (3), pp. 336-359, 2020. https://doi.org/10.1108/ET-01-2020-0006.
16. L. Page and L. Stanley, “Ergonomics Service Learning Project: Implementing an Alternative Educational Method in an Industrial Engineering Undergraduate Ergonomics Course”, *Human Factors and Ergonomics in Manufacturing* vol. 24 (5), pp. 1-13, 2014. http://doi.org/10.1002/hfm.20544.
17. D. Lombardi and T. F. Shipley, “The Curious Construct of Active Learning”, *Psychological Science in the Public Interest* vol. 22 (1), pp. 8-43, 2021. https://doi.org/10.1177/1529100620973974.
18. S. Freeman, S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt and M. P. Wenderoth, “Active learning increases student performance in science, engineering, and mathematics” in *Proceedings of the National Academy of Sciences* vol. 111 (23), pp. 8410-8415, 2014. https://doi.org/10.1073/pnas.1319030111.
19. P. C. Wankat,“Analysis of the First Ten Years of the Journal of Engineering Education”, *Journal of Engineering Education,* vol. 93 (1), pp. 13–21, 2004. https://doi.org/10.1002/j.2168-9830.2004.tb00784.x.
20. ABEPRO “Associação Brasileira de Engenharia de Produção”, 2023. Available: https://abepro.org.br/interna.asp?p=399&m=424&ss=1&c=362. [Accessed January 2023].
21. C. Andersson, G. Kroisandt and D. Logofatu, "Including Active Learning in an Online Database Management Course for Industrial Engineering Students," *2019 IEEE Global Engineering Education Conference (EDUCON)*, Dubai, United Arab Emirates, 2019, pp. 217-220. https://doi.org/10.1109/EDUCON.2019.8725065.
22. R. M. Lima, J. Dinis-Carvalho, R. M. Sousa, A. C. Alves, F. Moreira, S. Fernandes and D. Mesquita, “Ten Years of Project-Based Learning (PBL) in Industrial Engineering and Management at the University of Minho”. *In: Guerra, A., Ulseth, R., Kolmos, A.* (eds) PBL in Engineering Education. SensePublishers, Rotterdam, 2017. https://doi.org/10.1007/978-94-6300-905-8_3
23. A. Alves, R. Sousa, F. Moreira, M. Carvalho, E. Cardoso, P. Pimenta, T. Malheiro, I. Brito, S. Fernandes and D. Mesquita “Managing PBL difficulties in an industrial engineering and management program”, *Journal of Industrial Engineering and Management,* vol. 9 (3), pp. 586-611, 2016. http://dx.doi.org/10.3926/jiem.1816.
24. J. Nazarko, K. Anna Kuźmicz, E. Szubzda-Prutis and J. Urban, “The General Concept of Benchmarking and its Application in Higher Education in Europe*”, Higher Education in Europe,* vol. 34 (3-4), pp. 497–510, 2009. https://doi.org/10.1080/03797720903356677.

25. R. Dreher, "A benchmark for curricula in engineering education: The Leonardic Oath," in *2015 International Conference on Interactive Collaborative Learning (ICL)*, Firenze, Italy, 2015, pp. 722-724. https://doi.org/10.1109/ICL.2015.7318117.
26. FULBRIGHT COMMISSION, "Modernization of Undergraduate Education (PMG): Special project", 2023. Available: https://fulbright.org.br/special-project/modernization-of-undergraduate-education-program/. [Accessed January 2023].
27. M. A. C. Tinoco, L. C. P. Silva Filho, C. S. Ten Caten, J. S. Souza, A. M. Danilevicz, C. Nodari, D. R. Lima, C. C. Dutra, I. C. de Paula, and J. L. D. Ribeiro, "Redesenho do Currículo a partir da análise de Stakeholders no curso de graduação em Engenharia de Produção da UFRGS", *Planejamento e Primeiros Resultados dos Projetos Institucionais de Modernização da Graduação em Engenharia (2019/20),* Programa Brasil-Estados Unidos de Modernização da Graduação em Engenharia (PMG – Capes / Fulbright) ABENGE, 2021. Available: https://www.abenge.org.br/arquivos/downloads/livro/01_Livro-PMI-Abenge-2019-2020.pdf.
28. B. M. Olds, B. M. Moskal and R. L. Miller, "Assessment in Engineering Education: Evolution, Approaches and Future Collaborations". *Journal of Engineering Education,* vol. 94 (1), pp. 13–25, 2005. https://doi.org/10.1002/j.2168-9830.2005.tb00826.x
29. M. Borrego, E. P. Douglas, and C. T. Amelink, "Quantitative, Qualitative, and Mixed Research Methods in Engineering Education". *Journal of Engineering Education,* vol. 98 (1), pp. 53–66, 2009. https://doi.org/10.1002/j.2168-9830.2009.tb01005.x.
30. S. Daly, A. McGowan, P. Papalambros, "Using qualitative research methods in engineering design research" in *Proceedings of the 19th International Conference on Engineering Design (ICED13), Design for Harmonies*, vol.2: Design Theory and Research Methodology, Seoul, Korea, 2013, pp. 203-212.
31. R. S. Chauhan "Unstructured interviews: are they really all that bad?", *Human Resource Development International*, 2019. https://doi.org/10.1080/13678868.2019.1603019.
32. J. A. Leydens, B. M. Moskal and M. J. Pavelich, "Qualitative Methods Used in the Assessment of Engineering Education". *Journal of Engineering Education,* vol. 93 (1), pp. 65–72, 2004. https://doi.org/10.1002/j.2168-9830.2004.tb00789.x.
33. A. Trauth, T. N. Barnes, J. Buckley, J. A. Enszer, S. I. Rooney, R. Davidson and X. V. Zhang, "How Granular is the Problem? A Discipline-specific Focus Group Study of Factors Affecting Underrepresentation in Engineering Undergraduate Programs" *Paper presented at 2018 ASEE Annual Conference & Exposition*, Salt Lake City, Utah, 2019. https://doi.org/10.18260/1-2--30581.
34. A. L. Pawley, C. Schimpf and L. Nelson, "Gender in Engineering Education Research: A Content Analysis of Research in JEE, 1998-2012*". Journal of Engineering Education,* vol. 105 (3), pp. 508–528, 2016. https://doi.org/10.1002/jee.20128.
35. A. Winkens and C. Leicht-Scholten, "Competencies for designing resilient systems in engineering education – a content analysis of selected study programs of five European technical universities", *European Journal of Engineering Education*, 2023. https://doi.org/10.1080/03043797.2023.2179913.
36. D. C. Lantu, Y. Suharto, I. Fachira, A. Permatasari, G. Anggadwita, "Experiential learning model: improving entrepreneurial values through internship program at start-ups", *Higher Education, Skills and Work-Based Learning*, vol 12 (1), pp. 107-125, 2022.
37. J Tovey, "Building connections between industry and university: Implementing an internship program at a regional university", *Technical communication quarterly*, vol 10 (2), pp. 225-239, 2001.
38. D. Y. Chang and P. Y. Chu. "University-industry cooperation in action: A case study of the integrated internship program (IIP) in Taiwan", *Journal of Hospitality & Tourism Education*, vol 21 (1), pp. 6-16, 2009.