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Original article

Integrating Challenge-Based-Learning, Project-Based-Learning, and Computer-Aided Technologies into Industrial Engineering Teaching: Towards a Sustainable Development Framework

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Abstract

Introduction. Teaching industrial engineering in the second decade of the 21st century requires problem-solving and decision-making competencies oriented towards sustainable development. The growth of information metrics, the Internet of Things, virtual and augmented reality, and Artificial Intelligence bring more diverse, complex and imprecise challenges. This article aims to show a framework employing Challenge-based-learning, Project-based-learning and Computer-Aided technologies as dynamic resources supporting the comprehensive teaching of industrial engineers for industrial solutions oriented towards sustainable development.
Materials and Methods. Our research involved a systemic analysis of the framework variables, the stages, and the partial results of its application in three academic years research. We selected several case studies to evaluate the professional competencies related to Sustainable Development Goals of industrial engineering students, using active learning tools integrated with Computer-Aided technologies. These cases illustrated the acquisition of Sustainable Development Goals competencies. Two simultaneous Latin American scenarios were examined (Mexico and Cuba).
Results. Its main contribution is an appropriate framework for using Challenge-based-learning, Project-based-learning and Computer-Aided technologies as resources to develop professional competencies in industrial engineering and sustainable development. The control groups results demonstrate the utility, relevance, and accuracy of the proposed framework.
Discussion and Conclusion. The study of the theoretical and methodological components of teaching Industrial Engineering, emphasizing competencies, at two universities in Latin American countries revealed the need to understand Computer-Aided technologies as a complex process. The proposed framework considers Computer-Aided technologies per the typologies of selected competencies integrated into the curricular design, including Challenge-based-learning and Project-based-learning, oriented toward the Sustainable Development Goals. The authors' conclusions contribute to the development of active learning methods in engineering, supported by the application of CAD/CAM/CAE tools and focused on the fulfillment of sustainable development objectives. The materials of the article will be useful for the teaching of Industrial Engineering from a digital transformation perspective, contextualized in sustainable development environments.

Keywords: higher education, challenge-based learning, project-based learning, educational innovation, engineering education, sustainable development

Conflict of interests: The authors declare no conflict of interest.

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Научная статья

Интеграция проблемного обучения, проектного обучения и компьютерных технологий в преподавание организации промышленного производства: на пути к концепции устойчивого развития учителей

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Аннотация

Введение. В настоящее время для преподавания организации промышленного производства требуются навыки решения проблем и принятия решений, ориентированные на устойчивое развитие. Рост информационных показателей, интернета вещей, виртуальной и дополненной реальности, искусственного интеллекта порождает более разнообразные, сложные и неточные задачи. Цель статьи – показать структуру, использующую проблемное и проектное обучение, компьютерные технологии в качестве динамических ресурсов, поддерживающих комплексное обучение промышленных инженеров, ориентированных на устойчивое развитие.

Материалы и методы. Исследование включало системный анализ структурных переменных, этапов и частичных результатов его применения за три академических года исследования. Авторами были отобраны несколько тематических исследований для оценки профессиональных компетенций, связанных с целями устойчивого развития студентов – будущих промышленных инженеров. Проанализированы два латиноамериканских сценария (Мексика и Куба).

Результаты исследования. Изучение теоретических и методологических компонентов преподавания промышленной инженерии с упором на компетенции в двух университетах в странах Латинской Америки выявило необходимость понимания компьютерных технологий как сложного процесса. Предлагаемая структура рассматривает компьютерные технологии в соответствии с типологиями выбранных компетенций, интегрированных в учебный план, включая проблемное и проектное обучение, ориентированные на цели устойчивого развития.

Обсуждение и заключение. Выводы авторов способствуют развитию активных методов обучения в инженерии, поддерживаемых применением инструментов CAD/CAM/CAE и ориентированных на достижение целей устойчивого развития. Материалы статьи будут полезны для преподавания промышленной инженерии с точки зрения цифровой трансформации, контекстуализированной в условиях устойчивого развития.

Ключевые слова: высшее образование, проблемное обучение, проектное обучение, образовательные инновации, инженерное образование, устойчивое развитие

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Introduction

The accelerating demands of technologies (including mass production, globalization, marketing, and digitalization) make achieving comprehensive sustainable development complex. In this scenario, higher education institutions have become change agents and must adapt and reinvent themselves in various settings [1; 2].

In 2015, the United Nations General Assembly approved the resolution establishing the 2030 Agenda [3]. This resolution set 17 SDGs, structuring a reference framework for their practical application. Education for Sustainable Development (ESD) is part of SDG 4: high-quality education [1], that is focused on the inclusion of lifelong learning [4].

Sustainable development is a concept applied in various fields, public policies, research projects, and the thinking of the general population. As a trend, it is fundamentally related to climate change and inequalities in socioeconomic development. At the university level [5; 6], a better appropriation of sustainable development with a broad vision is necessary, along with indicators that help incorporate it into the teaching process [7].

The complexity of multidisciplinary integration of the sustainable development components [8; 9] is a challenge for its appropriation through university curricula. Furthermore, the dynamic nature and coherence of these components [10; 11], strongly influence employer demands. Therefore, knowledge integration must consider the ambiguity, complexity and dynamics of the sustainable development processes.

In Industrial Engineering programs, the practical nature of the educational goals and the broad graduate profile result in a field that ranges from theoretical knowledge of basic sciences to technical knowledge of engineering. This transition occurs at various educational levels, in different curricular dimensions, and multiple professional situations. The practical scenarios of the profession [12; 13] shape future professional skills. They are an ideal platform for analysis and problem-solving, focusing on local solutions that promote sustainable development.

It is evident in the literature that sustainability is integrated into most courses using a traditional approach, rather than using active methodologies, such as PBL and CBL active learning methodologies [14–16].

Contemporary educational models are oriented towards developing disciplinary and transdisciplinary skills [17] and rely on didactic techniques that favor these processes. Among these techniques, CBL and PBL constitute two pillars facilitating these objectives.

Literature Review

Félix-Herrán et al. employed the CBL technique in an academic semester of the Mechatronics Engineering program to develop disciplinary and transversal competencies in a business environment [18]. The authors reported significant results in competency-based education. Although the authors described the procedure, they did not analyze its correlation with using computer tools for engineering.

In another study, Portuguez Castro et al. described implementing CBL in an online course for undergraduate students in various specialties [19]. During the course, challenges related to the SDGs were presented to the participants. The results showed that the students generated sustainable business ideas to resolve problems. The use of CAx as a didactic support platform was not addressed in the study. Other authors, such as Gudoniene et al., focused on studying the implementation of CBL for specific SDGs, but in second-cycle studies [20]. Similarly, they did not deal with the CAx support necessary to develop professional competencies.

Authors such as McLain emphasize demonstration and experimentation as a fundamental pedagogical tool for acquiring and developing knowledge [21]. For their part, Frank et al. [22], Doppelt [23] and Chua et al. [24] expose the advantages of PBL, where students build their knowledge through metacognition and active learning guided by teachers. Similarly, Niiranen [25] and Qu et al. [26] express the benefits of "learning by doing" In these cases, the intensive use of professional engineering tools in digital design and manufacturing systems was not addressed. Cavalcante Koike et al. describe in their research the use of the PBL as a way to promote interdisciplinarity in engineering training programs [27]. The authors analyzed the role of interdisciplinarity and skills but did not address the competencies needed to use CAx in problem-solving for sustainable development solutions.

García-Ros et al. analyzed the application of a teaching trajectory evaluation model, from pre-university to curricular training in the first year of various engineering careers [28]. Although they examined several mitigating variables in the educational context, they did not check the inclusion of CAx. At the same time, they did not address PBL or other similar techniques.

Putra and Dewi addressed using PBL in the teaching of engineering [29]. However, their limited descriptive, qualitative was not a holistic study of the tool's application. Moreover, in the Mechanics of Machines course, Uziak and Kommula used PBL to teach the kinematic reasoning of plane mechanisms, concluding with positive results from the group point of view and fulfilling the planned objectives [30]. The authors did not focus on the use of computer tools for engineering to support these processes.

In another analysis, Garikano et al. prove an approach based on the principle of active learning in an instructional context with PBL and Computer-Aided Design (CAD) tools [31]. The authors address the learning of the basic skills of CAD systems among users at an elementary level of development, using PBL as a pedagogical approach. However, they only consider CAD teaching and not from a holistic perspective of CAx training in engineering.

Sánchez et al. test the application of PBL in the first years of teaching computer engineering, but do not address its relationship to mechanical and industrial engineering [32]. In an approach to applying CAD Systems, Berselli et al. report using PBL with CAD/CAE tools in an Automatic Machine Design course [33]. The authors only focused on designing prototypes and did not consider an integrated analysis.

Fernandes et al. analyzed a case study where PBL is applied in a Mechanical Engineering course [34]. The authors used CAx as a platform for evaluating the results. In that work, a systemic approach to problem-solving with considerations of sustainable development was not taken.

The bibliographic review confirms the need for transdisciplinary research, which combines active learning tools (such as CBL and PBL) with CAx to develop skills in Mechanical Engineering students, specifically aimed to solve sustainable development problems.

This article presents a framework that integrates CBL, PBL and CAx to develop professional competencies in students in the Industrial Engineering program. The case study method was presented through different research projects (university – enterprise) related to various sustainable development goals in two Latin American countries. Students' use of the proposed framework during three academic years resulted in a better appropriation of professional competencies than the control group. This research summarizes the primary, specific and transversal competencies articulated among the students in the context of sustainable development. This analysis illustrates the active learning strategies focused on the SDGs.

Materials and Methods

The core activity of the Industrial Engineering profession in the 21st century consists of the design (understood in its broadest sense) and construction of new systems, subsystems or products to respond to social and business needs. This process comprises a sequential number of activities that go from identifying the need to implement or develop a specific solution or product. It is usually taught by structuring content by disciplines and courses related to each other, which clarifies and reduces the complexity of its understanding and assimilation.

This work focused on the modeling stage, analysis, evaluation and prototyping of the products, which is at the core of the engineers' professional labor. The successful solving of engineering problems depends on various factors, mainly analysis and evaluation. Inadequate or inaccurate analyses can make the system or product ineffective or even cause serious failures or accidents.

The most prevalent reductionist models of engineering teaching are the deterministic ones, characterized by the intensive use of equations derived from scientific theory and praxis. To ensure that Industrial Engineering students improve their predictive capacity, numerical modeling and simulation techniques (CAx), combined with Engineering Analysis and Synthesis, are practical tools.

Design and settings. The research is related to the process of updating and professionalizing industrial engineering careers, based on social development and satisfying the needs of employers.

We selected several case studies to evaluate the professional competencies related to SDGs of industrial engineering students, using active learning tools integrated with CAx. These cases illustrated the acquisition of SDG competencies. Two simultaneous Latin American scenarios were examined (Mexico and Cuba).

Sample. In the Mexican case, we examined the Integrated Manufacturing Systems (IMS) course in the Engineering program at Tecnologico de Monterrey. In Cuba, it was the "Project III" course in the Mechanical Engineering program at the University of Holguin.

Ethical consignations. In the research, personal data were not collected. All the details in each case study, institutional and business, were handled with anonymity. Only public domain aspects and those with academic requirements were considered.

Data collection. The necessary data for this research came from implementations of CBL and PBL with CAx in both institutions. During the implementation, the principal teachers who were part of the study administered questionnaires and techniques to students to evaluate the progress of the solutions. All the data that was collected were anonymized by the teachers, applying statistical tools.

Instruments used. The theoretical conception of the framework was designed for teaching industrial engineering, using CBL, PBL and CAx techniques. The SDGs were the driving variables of the measurement process. The selection of the case studies was mediated by the natural interaction between the universities and the business environment, facilitating the adaptation of the competencies intended.

Three levels of professional competencies were set up: basic, specific and transversal, ranging from the general to the particular [35–37]. These three blocks were proposed for analyzing the professional development of the industrial engineering students using CBL, PBL and the CAx considering the SDG objectives. Correlations were considered from reverse planning, recognizing the profile (broad access) and standardizing procedures.

The students involved used the techniques and tools to develop the necessary competencies to perform correctly in local contexts.

Data analysis. The data were anonymized and analyzed according to the theoretical perspectives that were referent. The proposed framework used instrumental case studies. In this work, they allowed visualizing the results of appropriating competencies (basic, specific and transversal) in the context of the SDGs by the industrial engineering students. The university and enterprises were linked through research projects. Working with the business sector favored developing virtual and physical prototypes and modeling the industrial processes in real conditions.

Basic competencies (BCs):

– Develop autonomous learning strategies regarding the diversity and plurality of ideas, people and situations (BC 1).

– Generate innovative and competitive proposals in research and professional activity by solving mathematical problems that may arise in engineering. Ability to apply knowledge about linear algebra; geometry; differential geometry; differential and integral calculus; differential equations and partial derivatives; numerical methods; numerical algorithms; statistics and optimization; utilitarian aspects of Physics and Chemistry (BC 2).

– Implement the basic concepts on the general laws of mechanics, thermo-dynamics, fields and waves and electromagnetism and their application to solving engineering problems (BC 3).

– Use the programming of computers, operating systems, databases, and computer programs with applications in engineering (BC 4) satisfactorily.

– Capacity for spatial vision and knowledge of graphic representation techniques, both by traditional methods of metric geometry and descriptive geometry, as well as through computer-aided design applications (BC 5).

Specific competencies (SCs):

– Analyze data obtained through experimental tests (SC 1).

– Manage a mechanical engineering project, including planning, direction, execution, and evaluation (SC 2).

– Design mechanical elements and systems using computer-aided graphic design tools (SC 3).

– Develop mechanical elements, systems and products using CAD/CAM/CAE and PDM techniques (SC 4).

– Implement the fundamentals of fluid-mechanical systems and machines, graphic engineering techniques, materials engineering, calculation, design and testing of machines (SC 5).

– Apply basic and technological subjects, which enable them to learn new methods and theories, and give them the versatility to adapt to new situations (SC 6).

– Solve problems with initiative, decision-making, creativity, critical reasoning, and communication and transmit knowledge, abilities and skills in the field of organization by processes (SC 7).

– Carry out measurements, calculations, valuations, appraisals, studies, reports, work plans and other similar works, respecting rules and regulations (SC 8).

– Assess the social, economic and environmental impact of technical solutions and the university-business alliance (SC 9).

– Implement thermal engineering and the fundamentals of elasticity, the strength of materials to the behavior of real solids (SC 10).

– Apply manufacturing, metrology and quality control systems and processes (SC 11).

Transversal competencies (TCs):

– Learn new knowledge, techniques, methods and theories independently throughout professional life, from proper time management and work organization (TC 1).

– Manage the tools and means of communication and information processing provided by information and communication technologies (TC 2).

– Implement solutions from renewable energy and energy efficiency guidelines (TC 3).

– Apply the principles of Safety and Hygiene at Work, the techniques for assessing the risks of accidents, the appropriate measures and means for their prevention (TC 4).

Results

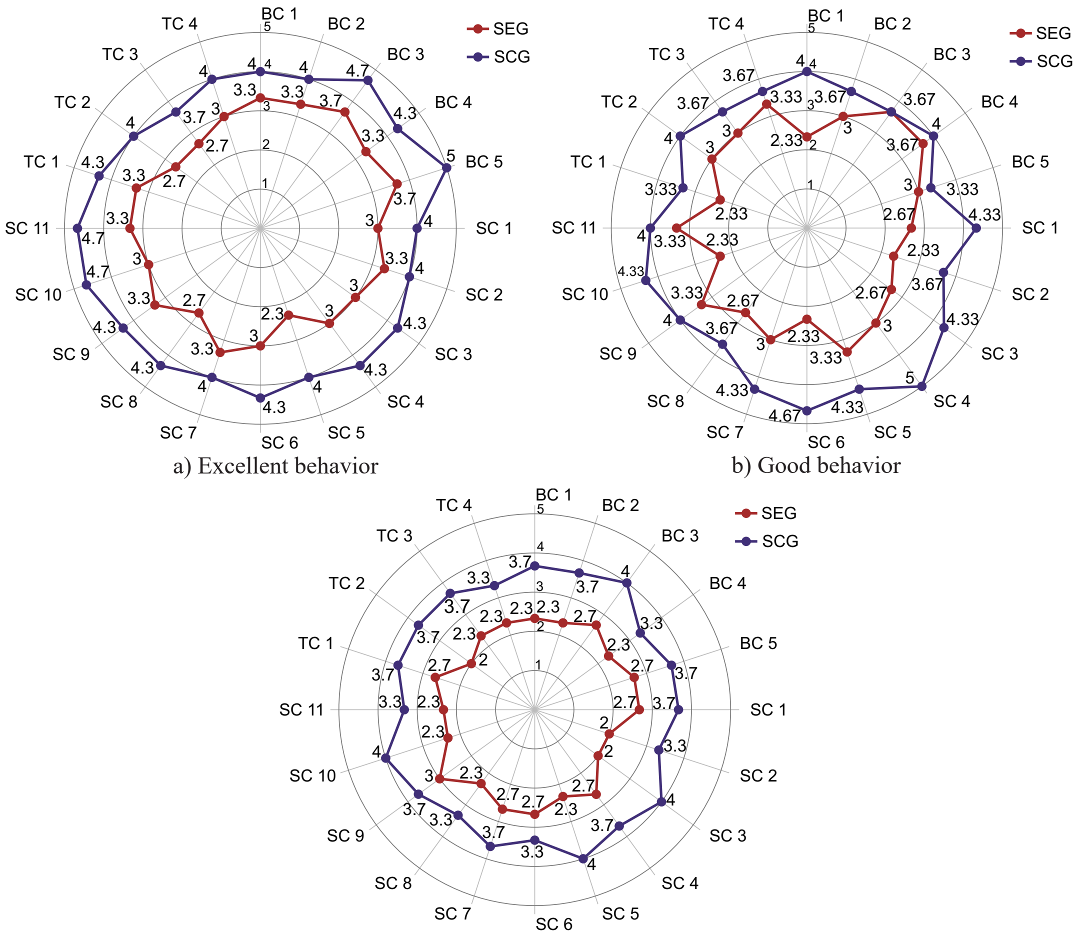
CBL and CAx applied in the IMS course at Tecnologico de Monterrey University in Mexico. This section presents the IMS as a case study to illustrate how the CBL and the CAx technologies were used as core components to promote the training and development of critical competencies in this field. The IMS course is part of the course offerings in the engineering programs at the Tecnologico de Monterrey University in Mexico. The primary purpose of this teaching-learning program is for students to learn about design methodologies, techniques, advanced technologies (machinery, equipment, tools), and 4.0 technologies (connectivity, “smartification”, virtualization, digitalization, datafication) in a manufacturing system; then, students will be prepared to identify and implement different technologies found in today’s IMS.

In engineering education, teaching-learning processes require the use of specialized infrastructure, including physical/virtual laboratories and tools, since they are necessary for the training of basic and specific skills/competencies and for experiential and practical learning [38]. In the manufacturing field, this scenario is complex since manufacturing systems are composed of different engineering components that encompass various disciplines such as mechanics, software, electronics, control, and management systems. Manufacturing is also considered one of the areas in engineering most aided by the 4.0 technologies. Therefore, this situation is challenging in the teaching-learning processes of these topics because pedagogical procedures and infrastructure must be constantly updated.

Henceforth, in the IMS course, these procedures are mainly based on active learning and modern ICTs platforms with virtualization/digitalization through 3D models and simulations to address all the related topics holistically.

CBL is the primary active learning tool. Students must design and develop a complete manufacturing system as a project during the academic period. To achieve this, the students design and manufacture a new product using the integrated product, process, and manufacturing system development (IPPMD) reference model framework. In addition, the students must consider the theory of sensing, smart, and sustainable systems (S^3 Systems) during the design processes to incorporate specific features, attributes, functions, and positive social impacts [39].

A random-stratified sample selection was carried out to analyze the competencies under study. Nine students learned under CBL and CAx, and nine were trained traditionally. It was shown that the arithmetic mean of all the grades by competencies and CBL cases indicated more significant development of the competencies. Figure 1 shows the prevalence of better results in almost all the competencies by students who received CBL teaching than traditionally. Also, these results show that by aligning the learning goals with the key competencies to be trained and applying the correct learning methods (such as CBL supported by ICTs and infrastructure), it was possible to design and develop an IMS project. This demonstrated that students could apply acquired knowledge and integrate core concepts in this engineering area. Table 1 summarizes the teaching-learning dynamic of this implementation.



a) Excellent behavior

b) Good behavior

c) Regular behavior

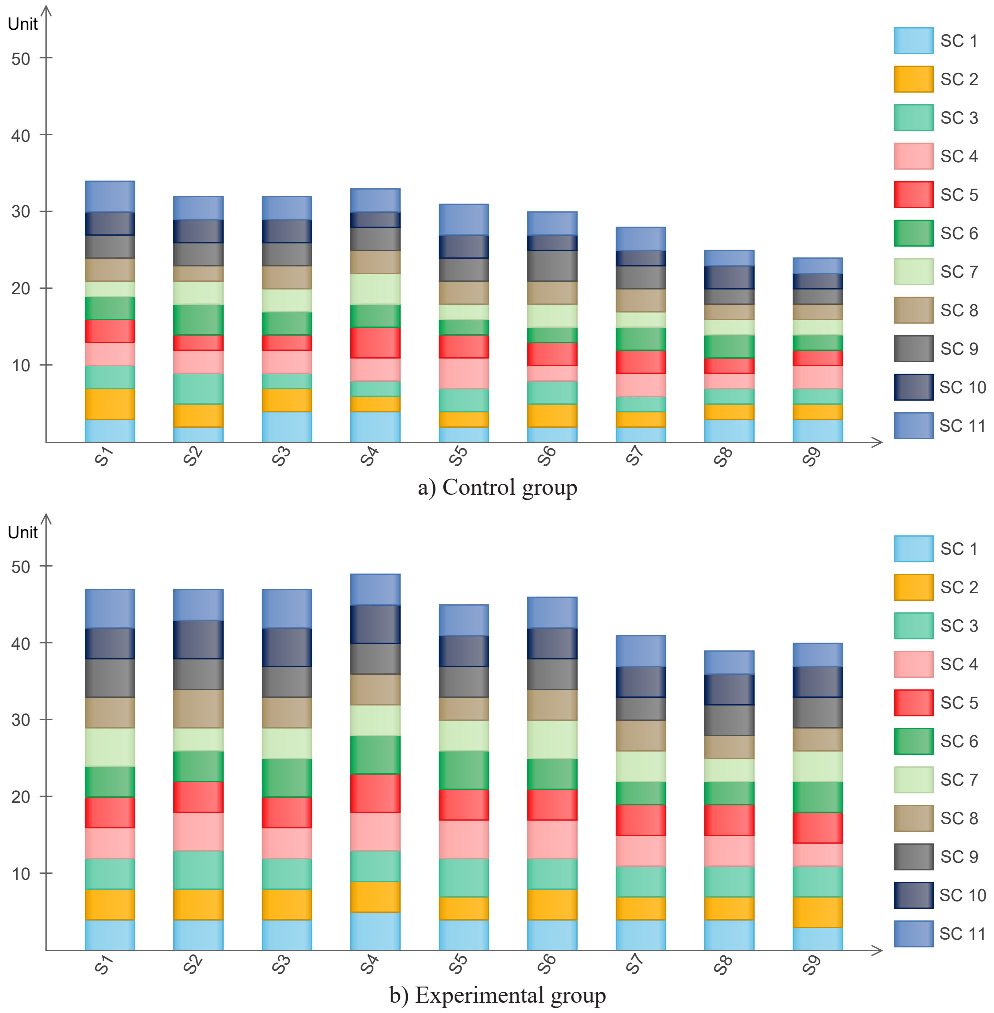
F i g. 1. Radial graphs presenting the arithmetic means of the competencies by strata, using CBL (SCG: Students from Control Group, SEG: Students from Experimental group)

T a b l e 1. **Main results achieved during three academic periods (2018–2020) in the Industrial Engineering program at Tecnologico de Monterrey, Mexico**

CBL Activity	Theoretical analysis	Practical result
A. Students are requested to design and manufacture a new product to provide a solution to social problems of the region, aligned to the SDGs	Use of the IPPMD reference framework model to develop physical and virtual prototypes, and the S^3 Systems theory	Through different development stages and applying concurrent engineering, the entities of product, process, and manufacturing systems are addressed and a toolbox (methodologies, techniques, CAx) is used as the main enabling resource

Topic A corresponds to an eighth-semester student in the Industrial Engineering program. In the subjects, the practical activity results correlate with SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-being), and SDG 7 (Affordable and Clean Energy).

The analysis by competencies and the accumulated frequency for each student trained by CBL with CAx confirm that all students' basic, specific, and transversal competencies increased. The most significant difference was observed in the specific competencies, as expected (Fig. 2).



F i g. 2. Cumulative bar graphs per student (nine students) of the specific competencies in the control group and experimental group, using the CBL tool (Sn: Student n for the study)

PBL and CAx applied in the "Project III" course at the University of Holguin in Cuba. In this section, the case study is the "Project III" course taught in the Mechanical Engineering program at the University of Holguin in Cuba. In the curriculum, it is an eighth-semester course that is part of the integrative discipline. This course illustrates how PBL and CAx favor the development of competencies oriented to the SDGs.

The discipline integrates disciplinary and transdisciplinary knowledge through integrative projects (such as "Project III"). In this way, the students fit in with the professional profile. Also, it gives students opportunities to work in groups and facilitates their developing capacities to solve problems independently. An important aspect is that it encourages developing technical, scientific information management skills and using ICTs, CAx, and other disruptive technologies.

To meet these objectives, PBL was employed as an active learning tool. Students must design and develop technological solutions as a joint research project between the university and the local industrial sector. Those problems that are identified within the SDGs are taken as a reference. To achieve SDG objectives, students have to use design methodologies and technological computer platforms for mechanical engineering and propose manufacturing technologies appropriate to local contexts.

To analyze the competencies in this study, we had a random-stratified sample selection. Nine students who received the integrated PBL and CAx were selected for the experimental group, and nine were trained traditionally. The arithmetic mean of all the grades by competency of the PBL students indicated a more significant development of the competencies. Figure 3 shows the prevalence of higher results in almost all the competencies in those students receiving their teaching through PBL than the control group (traditional).

Table 2 summarizes the main results obtained from applying PBL in the academic years 2017–2019, grouped by subject areas (energy, design and manufacturing). Topic A corresponds to a tenth-semester student in the Mechanical Engineering program, and topic B to an eighth-semester student. In both subjects, the practical activity results correlate to SDG 7 (Affordable and Clean Energy).

Topics C and D are taken by students in the eighth and tenth semesters, respectively. Topic E is taken in the tenth semester. In the practical activity results, topic C correlates with SDG 7 (Affordable and Clean Energy), topic D aligns with SDG 3 (Good Health and Well-being), and topic E links to SDG 2 (Zero Hunger), the latter developed at CEDEMA. Topics F and G (taken by tenth-semester students) correlate with SDG 9 (Industry Innovation and Infrastructure).

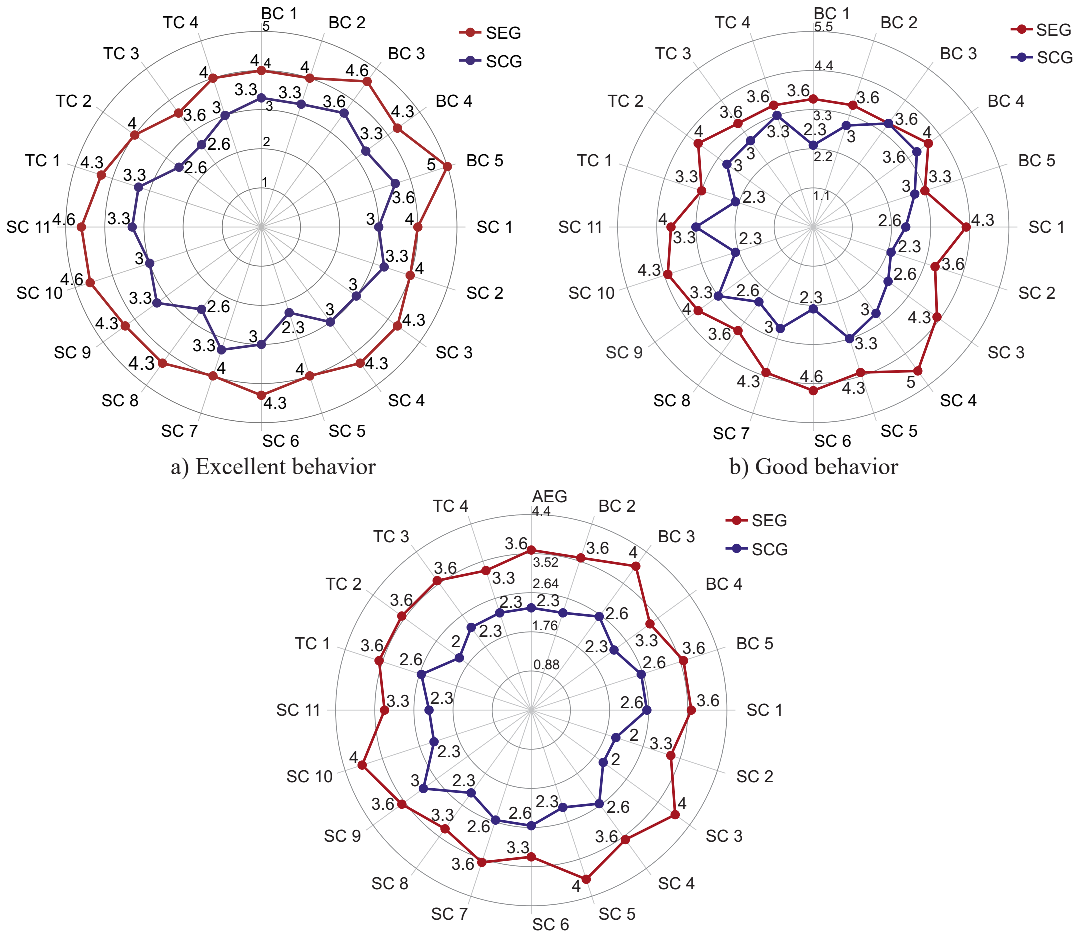
The analysis by competencies and their accumulated frequency for each student trained under PBL with CAx demonstrates that basic, specific, and transversal competencies increased among all the experimental students. The maximum difference was observed in the specific competencies, as expected (Fig. 4).

Professional performance assessment. By using the CBL tool with CAx, the professional performance can be measured and evaluated by using mixed–methods:

1. For the quantitative analysis, the students completed two sets of surveys (a pre-survey before the course and post-survey after).
2. For qualitative analysis, the student's work in evaluating the obtained product, process, and production system was analyzed.

Figure 5 presents the results based on the answers of 54 undergraduate students in the Industrial Engineering program at Tecnologico de Monterrey during three academic periods (2018–2020). The graphs compare the two surveys on the students' perception about their professional training in other engineering courses versus the training in these courses. The results show that most students perceive that the encouraged professional performance increased by doing the proposed integrated project.

For external assessment, a sample of 16 students belonging to business and academic entities in the Province of Holguin participated in evaluating the PBL and CAx tools. In all cases, employers were more satisfied with the experimental students' performance than with their counterparts trained traditionally and who work in these companies.



a) Excellent behavior b) Good behavior

c) Regular behavior

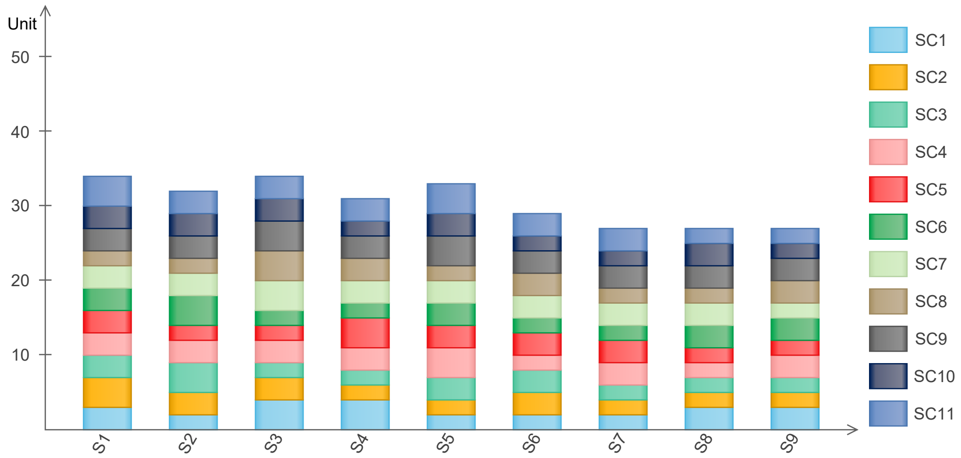
F i g. 3. Radial graph that presents the arithmetic means of the competencies by strata, using the PBL tool (SCG: Students from Control Group, SEG: Students from Experimental group)

T a b l e 2. **Main results achieved during the 2017–2019 academic years in the Mechanical Engineering program at the University of Holguin, Cuba**

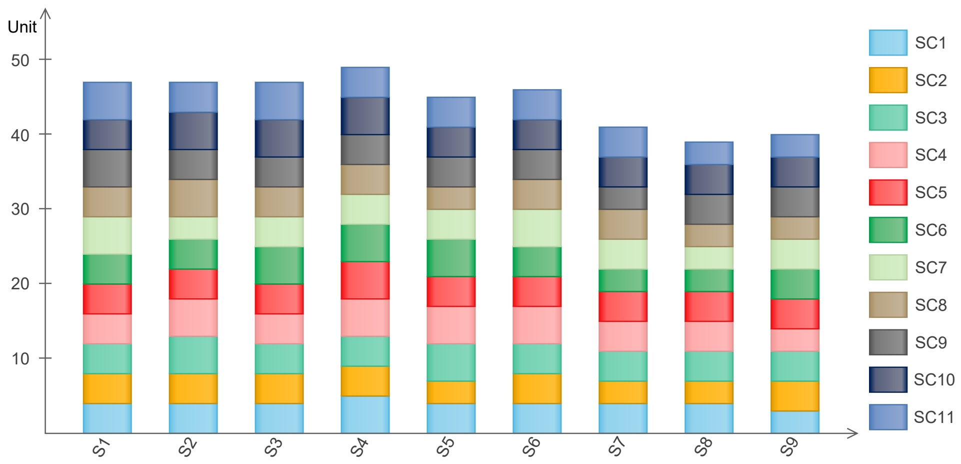
CBL Activity	Theoretical analysis	Practical result
1	2	3
Subject: energy		
A. Procedure for the design of the Piston-Connecting Rod-Crankshaft mechanism of a compressed air engine	Numerical simulation that allows the determination of the geometric relationships that ensure optimally working parameters	A procedure for the design of the mechanism. The sequence is: the process to be modeled, the systemic analysis, the CAD/CAE simulation, the linear optimization and verification of the result
B. Prediction of the power generated by a wind turbine: a complex multi-factorial process	Identification of factors, (of a complex nature and stochastic behavior that determine electricity generation. A model based on Markov chains was used	A mathematical model that supports an electric generation power estimation procedure (applied in real conditions of the Gibara I Wind Farm in Holguin
Subject: design		
C. Optimal water pump design	A method that allows the design of the optimal dimensions of the pump through CAD/CAE/CFD simulation	An autonomous water pump

End of table 2

1	2	3
D. Standing frame model for children with Infantile Cerebral Palsy	A method that considers the physical limitations and the size of the child to determine the dimensions and its CAD design	Virtual prototype (CAD/CAE) of custom standing Frame
E. Modeling of interfaces	Modeling of functional requirements for the design of a rice mini-harvester for the business sector	Modeling of the requirements (CAD) of a mini rice harvester (applied in real conditions of the Agricultural Machinery Development Center (CEDEMA) company)
Subject: manufacturing		
F. Pouring ferrous and non-ferrous metals	Method for the design and manufacture of a vibrating platform for the smelting of ferrous and non-ferrous metals	Design and construction of a vibrating platform (CAD/CAM/CAE) for casting parts (applied in real conditions at "Fundiciones Holguin")
G. Design of progressive cutting Dies	Optimal multiple objectives design and progressive cutting dies design	Design of a progressive cutting dies based on CAD System

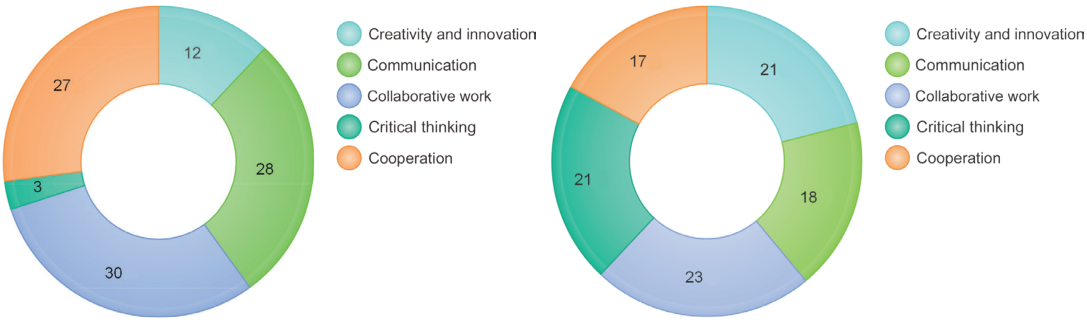


a) Control group



b) Experimental group

F i g. 4. Cumulative bar graph per student of the specific competencies of the control group and experimental group (using the PBL tool) (Sn: Student n for the study)



a) Trained before the courses b) Trained after the courses

F i g. 5. Doughnut graphs showing the two survey results comparing professional performances during three academic periods (2018–2020), %

Table 3 shows that employers did not perceive that any student in the experimental group had little adaptation in their professional skills (low performance). Similarly, comparing 2017 and 2018, it is observed that the performances of those receiving PBL and CAx training increased (24.4%) with respect to those of the previous year with traditional training.

Discussion and Conclusion

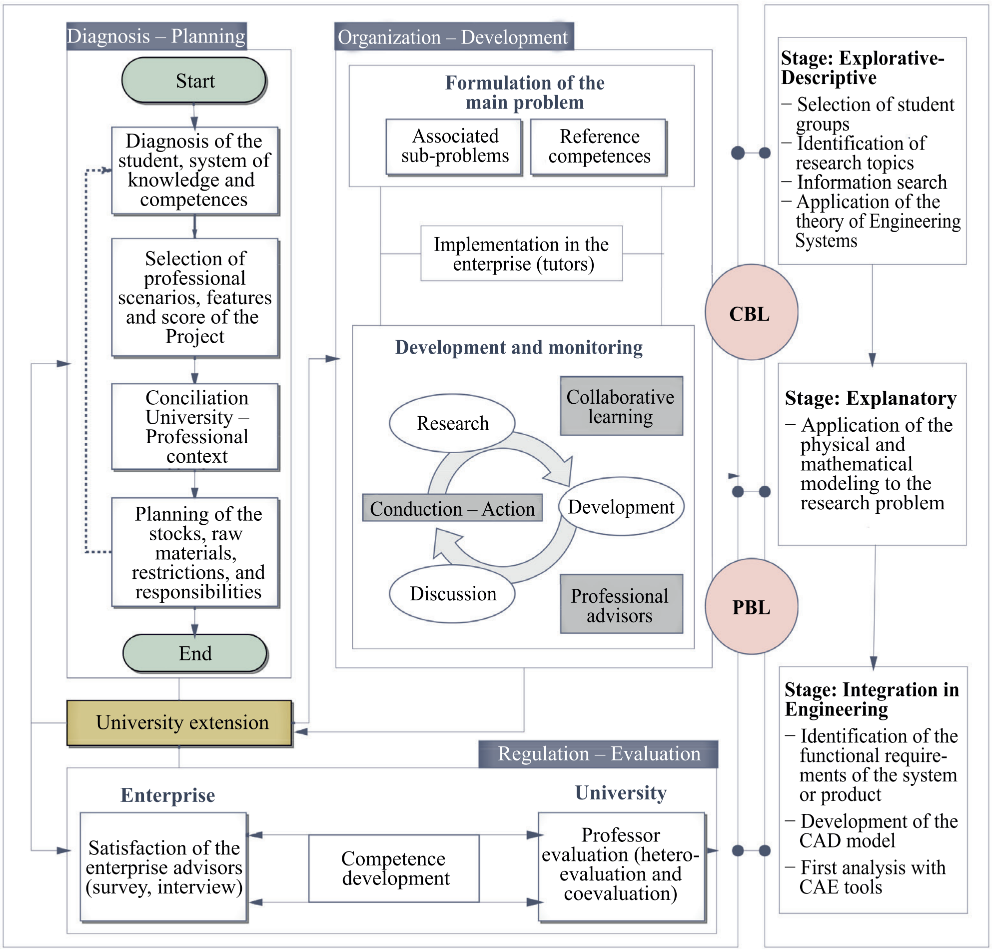
The broad professional profile of the Industrial Engineer in the 21st century is very comprehensive and varied. Essentially, it manifests intrapersonal, interpersonal, and technical performances. Wide application of CAx in the different stages of the product life cycle is notable. The Analysis and Synthesis of Engineering Systems is not used frequently in the teaching of the industrial engineer as an integration tool. This tool is designed to develop systemic thinking oriented to decision-making.

The findings of this study reveal that the proposed framework for teaching industrial engineering, integrating CAx with CBL and PBL, can be an effective method to increase students' perceptibility of SDGs. Figure 6 presents the most significant aspects of the proposed framework. The framework has three subsystems: diagnosis-planning, organization-development and regulation-evaluation. The subsystems in their dynamics have a self-contained function, but at the same time, in their synergy, they generate integration and optimization of competencies. In effect, they are proactive by recognizing various factors that can disrupt the system and, thus, generate states of resilience. These qualities support the professional performance of the Industrial Engineers using CAx in their work for sustainable development and the SDGs.

The diagnostic–planning subsystem has the function of recognizing the students' previous conditions. Therefore, it has four activities to guarantee human, material, and financial resources to use with CBL, PBL and CAx. In the same way, it contemplates the conciliation of legal and ethical aspects necessary in a university-enterprise negotiation process. On the other hand, the organization-development subsystem has the function of synthesizing and implementing the CBL and PBL with CAx to teach Industrial Engineers the competencies.

T a b l e 3. **Employer satisfaction with the training of mechanical engineers**

Didactic treatment	Year of employment	Very No.	Suitable, %	Suitable No.	%	Inappropriate No.	%
Traditional (18)	2017	8	44.4	7	38.9	3	16.7
Experimental (16)	2018	11	68.8	5	31.2	0	0

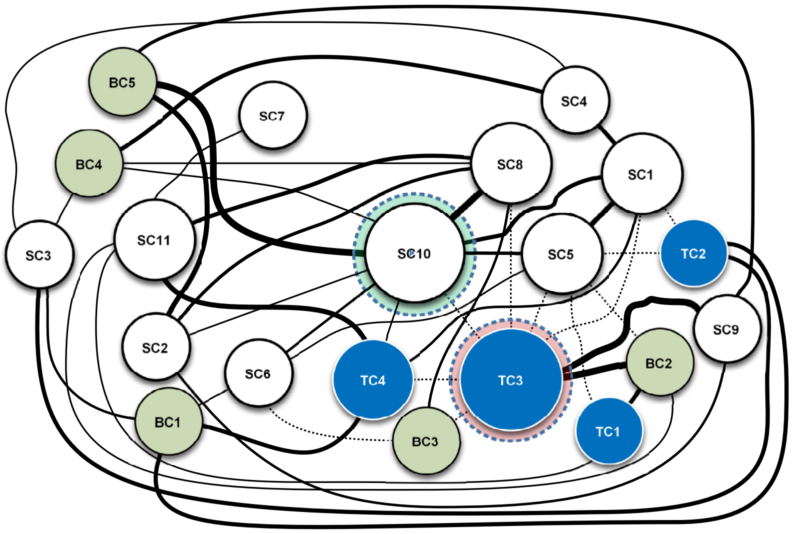


F i g. 6. Framework for integrating CBL, PBL and CAx to develop professional competencies oriented towards SDGs

This subsystem represents the natural integration of the substantive processes of higher education (teaching, research and extension) within the framework of the university-environment relationship. The structuring of this key subsystem contains activities that emerge from the dynamics of CBL and PBL. The last part of the project (due to its importance) occurs in the regulation-evaluation subsystem, which has a coordinating function. This subsystem works to mediate the economic, social and environmental impact of the university's actions. For this function, the last activities of the CBL and PBL were designed.

The framework requires a comprehensive preparation of teachers (both tutors and employers) and a multidisciplinary group to answer all the questions arising during the research or implementation. The results are assessed externally with criteria provided by the employers and internally, through the partial comparison of the students' competencies.

Using the correlation matrix of the three types of competencies analyzed in the research, the following analysis (Fig. 7) identified the possible associations between competencies, intensity, and direction (direct and inverse). In general, Figure 7 shows solid associations and connectivities of knowledge for a better understanding of the behaviors identified in the teaching process by competencies of the engineers (in both institutions analyzed). Concerning CAx, the typologies of competencies are shown by colors (green, white and blue, for basic, specific, and transversal, respectively).



F i g. 7. Graphical modeling of the associations, intensity, and sense of the possible connections among the competencies using the proposed framework

Likewise, when the connection is stronger (i.e., it has values closer to 1 or 1), the segment thickens, indicating significant correlation (intensity) regardless of the direction. In the same way, the solid lines announce a positive and direct sense of correlation, and the dashed lines refer us to negative correlations and inverse effects.

The competencies that most influence the evaluated process are almost always centralized to show many associations studied. Specific competencies are energized with the most significant quantity and quality associations. The size of the circle represents the number of interconnections (the larger the connection, the larger the diameter of the circle identifying it).

Multiple correlations are shown with two basic nuclei. A positive one is direct, such as the specific competency SC10. This nucleus indicates that it could be a guideline for curricular design with intradisciplinary nature and suitable for CAx.

In the negative sense (inverse), another nucleus is distinguished, represented distinctively by the transversal competency TC3. This transversal competency from the study reveals that it must be controlled or adjusted in relation to the others. The study identifies that if its application for creativity, design, and algorithmizing processes is strengthened, it can be an element that retards the development of other competencies.

Without reducing the importance of this transversal competency, we must study its quantitative relationship with the other competencies in greater depth. Its treatment within the core of competencies for teaching Caz to industrial engineers should be handled carefully. Therefore, this study proposes that TC3 remains an essential restriction for problem-solving by the engineers using CAx; its scope and need must be defined.

Consistent with these reflections, Figure 7 reveals seven competencies with significant bilateral correlations (related to five or more competencies). They are SC10, SC3, SC8, SC11, SC1, SC5, TC4.

The analysis carried out with the experimental groups of students in two institutions in Latin American countries evidences the above. Using this study's framework, we showed that the competencies in the basic typology are essential to develop new knowledge due to logic and the development of competencies. The specific competencies have a greater responsibility in teaching industrial engineering using CBL and PBL as active learning tools and CAx as technological support.

The study of the theoretical and methodological components of teaching Industrial

Engineering, emphasizing competencies, at two universities in Latin American countries (Mexico and Cuba) revealed the need to understand CAx as a complex process. The proposed framework considers the typologies of selected competencies, with the use of CAx, by means of the curricular design by competencies and the PBL-CBL in the context of the SDGs.

The results of the experimental groups under the proposed framework show the appropriateness of using CBL and PBL with CAx to develop professional competencies oriented towards the SDGs. The assessment of the relevance and feasibility of the proposed framework was evaluated highly by the employers and experts. These results were validated through industrial case studies, in the local contexts of both countries.

With the use of the developed framework, it was evidenced that the competencies of the basic typology (BCs) are essential for the development of new knowledge. It was shown that the specific competencies have a greater responsibility in the teaching of industrial engineering, using CBL and PBL as an active learning tool and CAx as technological support.

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