A Matrix-Based Guideline to Chemical Engineering Curricular Revision

Design-Based Research

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Abstract—The objective of the study is to describe our matrix-based guidelines in revising our competence-based curriculum. A curriculum restructure relies on pragmatic and iterative refinement of the situations integrating various stakeholders' perspectives as well as field-based research by considering currently critical and emerging trends, such as the inclusion of the 21st century skills. The revision project took a 150-day duration and implemented the subsequent stages: 0). Build a common language 1). Identify aspects that are working well at the moment and those that may need revision in the current curriculum, 2). Align the performance indicators using the evaluation matrix, 3). Select types of learning activities that correlate with Bloom's taxonomy verbs, 4). Incorporate student learning autonomy into the curriculum. The matrix was used to facilitate equal, organized, and clearer distribution, thus, bringing the coherence of indicators for the 5-year progressive learning courses. The contribution of the study is to achieve comprehensive, systematic, and continuous improvement of the competence-based educational model for Latin American universities within engineering study programs.

Keywords—curricular revision, 21st century skills, Competence-based Curriculum (CBC), competency mapping

1 Introduction

Due to the 21st century global transformations, the 21st century engineering education requires current and future community of engineers to faithfully self-improve and innovate their practices through lifelong learning with emphasis on critical reflection, self-regulation, and self-organization [1][2]. Currently, we are in a time characterized by the provisional nature of knowledge, where content as an objective of teaching and learning no longer possesses the same previous value due to its ever-changing contexts [3][4][5].

Consequently and inevitably, higher education institutions today should incorporate various and constant changes into their institutional mission through quality professional training. The need has been seen in curricular renewal to actively update study plans and related training based on competences in curricular design, teaching practices and evaluation, in terms of the comparability of the accreditations of higher education degrees [6][7]. This curricular revision was driven by the need for engineering curricula to be more engaging and relevant reflecting currently best pedagogical practices.

Therefore, different countries and universities, including those in Latin America are beginning to revise or restructure their educational models and curricula. An example of this is the *Alfa Tuning Project* in Latin America [8]. The project was started as a higher education project in Europe, and then, spread to Latin America, with the goal to collaboratively create a common educational structure with measurable, reliable, and, of course, employable skills. The purpose of the project was to standardize Generic Competences; Specific Competences; European Credit Transfer and Accumulation System (ECTS) Credit Value [9]; and Teaching and Learning Approach, and Quality Assurance and Control. Due to the increasing globalization of education, many non-European countries and universities are beginning to establish educational models based on competencies [6][7].

If higher education study programs are the core of lifelong learning, it is then necessary and inevitable to reconsider our educational commitments that look towards the future. This is because educational institutions cannot remain in the present but rather radiate excellence and live the culture of the quality of educational processes to achieve better results [5][6]. Our university, UTEC, for its part, has revised its study plans to implement a model based on competencies in its 12 new, renewed and updated curricula meshes that guarantees its students to acquire needed knowledge, skills and attitudes (K-S-A) according to the social and labor demands, both at the local and global levels.

Recently, the Chemical Engineering study program at UTEC renewed its ICACIT accreditation - a process where a program is evaluated to determine if the respective study program meets this agency quality criteria. The Institute for Quality and Accreditation of Computing, Engineering and Technology Programs or *Instituto de Calidad y Acreditación de Programas de Computación, Ingeniería y Tecnología* (ICACIT) as a member of the Washington Accord, is an accrediting agency specialized in professional training programs in computer science, engineering and engineering technology to promote continuous improvement of the educational quality of the programs, ensuring that they meet the highest international standards that ensure that graduates are ready to practice their profession. The competence-based curriculum matrix-based guidelines refers to the work plan specifically designed to train to guarantee an intentional learning path that would allow the formation of the current graduate profile. The work plan allows autonomy on the part of the study programs and continuous learning to be able to start the process when they wish.

Numerous studies drawn from integrative reviews have discussed various viewpoints of Competence-Based Education (CBE) in terms of among which are the K-S-A (Knowledge, Skills, and Attitudes) design and development; authentic assessment and evaluation practices; curriculum renewal; and the inclusion of the 21st century skills [10][11][12][13][14][15]. Despite the respective integrative reviews in the aspect of curriculum change sustenance, competency frameworks, and curriculum renewal, the creation of a *practical* guideline to revise curriculum using aligned indicators and matrix in Chemical Engineering study program has not been addressed and constructed thus far.

The objective of the research is to describe how we identified aspects that require revisions, aligned the performance indicators using our Competency Mapping, selected types of learning activities that correlate with Bloom's taxonomy verbs, and eventually, incorporated student learning autonomy into the curriculum. The contribution of the study is a practical guideline for revising the 5-year Chemical Engineering curriculum by utilizing the resources or tools previously mentioned to facilitate the process of developing measurable and reliable competency matrices (with periodical renewals) as a model for other universities in Peru or Latin America. Beyond Latin America, the underlying principles of the alignment, the methodology, and the resources could also be utilized across global universities, possibly with some adjustment.

2 Theoretical framework

2.1 What is Competence-Based Education (CBE)?

The Competence-Based Education (CBE) method has been around since the 1970s [16]. As a result of its long existence [17], multiple definitions have also been around [18], and no universally shared or accepted definition and standardized implementation of CBE are present [18][19][20]. Despite its long existence, in fact, CBE was only piloted in 10 U.S. higher education institutions [21][22].

According to Kouwenhoven [23][24], Competence-Based Education (CBE) has several subsequent characteristics. First, CBE focuses on future professional practice. Second, CBE involves a learner-centered approach stimulating the use of materials that are highly individualized, flexibility in learning time, and feedback continuity to learners. Third, knowledge is obtained through active construction (constructivist approach). Fourth, the teacher functions as a cognitive guide to help students in their active inquiry. Fifth, CBE is oriented to acquiring and developing targeted competencies by the end of course. Sixth, CBE is aimed at achieving three goals of "determination of the disciplinary and functional subject areas, development of general skills or competencies, development of the capability of learning to learn" (p. 8) [24]. The three goals are to be achieved using innovation focus, problem solving and the elaboration of problems; self-reflection, and self-assessment. Seventh, CBE is oriented to formative and summative assessment of competencies. Ultimately, CBE is drawn from identifications of competencies needed by competent professionals. Based on the reference from Gervais as cited from page 99 [18] CBE is defined as "an outcome-based approach to education that incorporates modes of instructional delivery and assessment efforts designed to evaluate mastery of learning by students through their demonstration of the knowledge, attitudes, values, skills, and behaviors required for the degree sought." Our university definition of CBE reflected in our Competence-Based Curriculum (CBC) includes each and every respective definition of CBE along with the inclusion of the 21st century skills focusing on Cognitive Competencies, Interpersonal Competencies, and Intrapersonal Competencies [25].

2.2 Competence-based education models

Several generic and research-based models needing both standardization and individualization of education for CBE design have been suggested by Wesselink, Biemans, Gulikers, and Mulder [26]. The first model is of Van den Berg and De Bruijn [26]. According to the model (p. 537), CBE is characterized by four aspects of, 'learning by self-steering,' 'learning in the workplace/workplace learning,' 'meaningful learning,' and 'flexibility.' [26]. Learning by self-steering requires that students are responsible for their own learning and their future career navigation. Meanwhile, workplace learning emphasizes more time spent in the workplace essential to overcome the existing gap between education and employment. Meaningful learning encourages the use of reflection drawn from learning outcomes of the workplace. Ultimately, flexibility focuses on the adjustability of the instructions and contents of the learning trajectory.

The second CBE model is drawn from Gruppen et al. (2012) [27] with the framework design and implementation focus on the desired performance of healthcare professionals [26]. The framework is based on five characteristics: 1). Competence focuses on the instructional goals performance; 2). Competence is the fulfillment of external stakeholders' expectations outside the educational programs; 3). Competence is demonstrated through measurable behavior (integrated elements of knowledge, skills and attitudes concluded from educational experiences and curriculum); 4). Competence is based on standard of learning outcomes determined by the field practitioners and educators; 5). In the end, competence should be accessible and remain transparent for learners, stakeholders, and policy makers.

The third CBE framework, namely, Comprehensive Competence-Based Education (CCBE) model is that of Sturing et al. (2011) [28], derived from Wesselink et al.'s model [26]. The model is the only framework that describes various CBE 5-level implementations (with ten CBE design principles) to fortify or buttress the CBE development ranging from "not competence based to completely competence based" (p. 538) [26]. The ten levels of implementation are foci set on core tasks, working processes, and competencies; complex vocational core problems; concrete, meaningful vocational learning situations; integrated Knowledge, Skills, and Attitudes (K-S-A); regular assessment; student learning reflections; study programs encouraging student learning autonomy; flexible study program; existence of student-based learning needs guidance; and finally, prioritization of learning, career and citizenship competencies.

2.3 The importance of (competence-based) curricular revision and practical guidelines

Competence-Based Curriculum (CBC), in contrast to traditional curriculum, provides students with specific skills development in the form of learnable units of competences. In addition to this characteristic, CBC is more student centered with its adaptive learning possibility –continually evolving personalized learning with multiple pathways to graduation – in order that none of the students are left behind [22][29][30]. Whereas traditional learning is often generic, thus neglecting the uniqueness of each student taken into learning [29]. Since CBC is student centered, the time is also flexible and students can progress in either modes – individually or in small groups where an instructor acts as a coach or a mentor [29]. CBC is organized under practically oriented modules and "theory is taught mainly as underpinning knowledge usually at a workshop and workplace or in a simulated environment" (p. 4) [29]. Traditional learning focuses on theoretical knowledge acquisition with practical training simultaneously performed by all students in a traditional class setting. Ultimately, CBC offers students an assessment tailored to "clearly specified criteria or standards in the industry" where the achievement of the learning outcome is criterion-referenced – drawn from the fulfillment of a single performance criterion (p. 5) [29]. Meanwhile, traditional learning assessment is drawn from written tests and practical assignments – in comparison with other students using norm-referenced assessment whether students pass or fail.

Prioritizing technical skills or competencies for students' future employment is, of course, essential; however, the skills may not be able to compete with the high acceleration of technology and mobility in the workforce of today [29]. Although raising technical skills of the workforce is important, it is not adequate in the context of the rapid pace of technological change and high labor mobility. Exposing students to a job-specific task may hinder their future employability given the fact that the students are only exposed to routine and restricted tasks [31]. Thus, students should be equipped with transferable 21st century knowledge, skills, and attitudes that are grounded in student-centered, relevant, authentic, constructive and interdisciplinary innovations and creativity through deeper learning in order that they eventually can secure broader employability [5][32]. Apart from the opportunities offered by the CBC, the CBC global implementation also had its share of challenges in the past few years, in terms of inter-institutional credit transfer; cooperation with industries; calibration of knowledge, skills, and attitudes (K-S-A); increasing complexity of today's work nature; and flexibility or inflexibility in specifications of competences in response to the 21st century professional demands [8][33][34][35][36][37][38][39][40][41]. Despite these challenges, curriculum reform or renewal is inevitable to respond to the fluid professional demand of today requiring continuous innovation and quality improvement.

Learning, according to Dewey [42], occurs best when students are engaged in meaningful and significant experiences. These meaningful and significant experiences could be attained by giving students active exploration opportunities in socially situated learning contexts through peer and expert interactions to develop their metacognitive skills [43] through scaffolding where the difficulty of assigned tasks is still both challenging and manageable [43][44]. Chemical engineers of the future are expected to possess the following characteristics, such as technological and social competences, problem-solving skills, strong logical reasoning, and eventually entrepreneurial skills [45]. In order that the expected core competences can be achieved, the constructivist approaches (student-based learning), among which are Inquiry-Based Learning (IBL), Project-Based Learning (PjBL), Inquiry Project-Based Learning (Inquiry PjBL), Problem-Based Learning (PBL), and/or Constructionism, need to be evidently present in our curriculum renewal [46].

Knowledge and skills do not exist in a vacuum and they should extend beyond traditional classrooms and connect with their applicability and engagement in the community. Five aspects of "accreditation standards, education models, professional associations, industry needs, and globalization" drive our university to reform our curricula (p. 306) [7]. Well-known engineering education frameworks frequently used are the CDIO (Conceive, Design, Implement, Operate) initiative and the ABET model [7]. In our case, the educational frameworks used are derived from those of Bloom's Taxonomy as well as of ICACIT (based on the ABET model).

Despite the existence of CBC for decades, the literature regarding Chemical Engineering study program curricular revision has not caught much attention, especially, in terms of the existence of pragmatic guidelines of alignment to execute curricular revision, redesign, or renewal, in a systematic way. Henri, Johnson, and Nepal reviewed engineering education from 2005-2015 addressing different approaches used in Competency-Based Learning (CBL) implementation, CBL pedagogical effects on learning outcomes, CBL effectiveness enhancement tools, and finally, CBL assessment strategies [47]. Yet, none regarding specific guidelines has been designed thus far to *practically* guide the Chemical Engineering curriculum to advance the differentiation in the 21st century, let alone for the 5-year undergraduate program in Latin American higher education institutions. So far, only course-related revision within curriculum has promoted the implementation steps of the new graduate education curriculum model [7].

It is high time that our university offered this rigorous curricular revision to invest and advance differentiation in the future of our students [48]. Rigorous curriculum is a curriculum that supports learners to grow intellectually where they are buttressed with opportunities to maximize their knowledge, skills, and abilities. To be rigorous, a curriculum should be inquiry based, relying more on concepts, involving critical thinking, instilling creativity, necessitating problem discovery and solution, infusing knowledge application, encouraging reflection, and eventually, incorporating assessment for and of learning [48]. Regular curricula review and enhancement is of pivotal role in maintaining the standards of undergraduate programs since the field of engineering education lies in the intersection of technological innovation and engineering curriculum [49]. Thus, the constancy to update curricula needs to remain present, evident, and sustainable.

3 Background information

UTEC, despite its young age, always attempts to attend to the profile of its students, based on their ability to innovate and undertake, facing the local and global challenges of the 21st century. The holistic, reflective, and competent training for decision-making that we propose is intertwined with the curricular mesh transdisciplinary integrating knowledge and solid foundations that govern our schools of engineering, computing and business management and integrated with courses that are based on ethics, empathy, sociology and the global approach summarized in the following seven points:

a) Interdisciplinary Certification: Curricular flexibility through an offer of effective courses that include interdisciplinary certification that will allow the student to explore other disciplines.
b) Interdisciplinary Projects: Search for the integral training of the professional through projects that generate solution proposals to the challenges posed using engineering tools in which various disciplines converge.
c) Research: Establishment of more activities and research projects that generate new knowledge and have a real impact on society.
d) English as a graduation requirement: We promote professional training through the English language, to optimize levels of international competitiveness and reinforce global skills.
e) The 25-hour volunteering as a graduation requirement: Establishment of more activities and research projects that generate new knowledge and have a real impact on society.
f) Curriculum mesh reduction up to 200 credits: We promote professional training through the English language, to optimize levels of international competitiveness and reinforce global skills.
g) The 20% virtuality: Hybrid education establishment. Up to 20% of courses are to be delivered virtually, while providing flexibility, we will use technology to achieve and consolidate learning.

The mission of the Chemical Engineering Department is firstly, to provide Chemical Engineering students with a strong technical education and communication skills that will enable them to have successful careers in various industrial and professional environments in Peru as well as worldwide. Secondly, the mission is to prepare Chemical Engineering students for rapidly changing technological environments with the core knowledge of multidisciplinary development and personal improvement throughout their professional careers. The ultimate mission is to instill a strong sense of humanistic values and professionalism in our students, such that they can impact ethically and knowledgeably in tackling societal issues.

UTEC undergraduate programs are organized to be completed within 5 years or 10 semesters. In the first year, basic concepts and fundamentals of each study program are presented. During the second and the third years, a period of in-depth knowledge of each specific study program starts. Simultaneously, students carry out interdisciplinary activities to develop skills in contextual projects. In the fourth year, the study plan provides a Real Life Experience (RLE) where the focus is to be on an external experience of the student's choice (internships, exchange programs, research projects, and entrepreneurship). In the last year, students are expected to complete their thesis projects. The fifth year is the period for the development of electives leading to the chosen interdisciplinary specialization and certification.

Figure 1 illustrates UTEC curriculum mesh with its different transversal areas that allow the formation of a holistic and comprehensive graduation skills in Sciences, and

Humanities-Arts-Social Sciences (referred to as HACS in Spanish), and Interdisciplinary Projects and Management.

Year 1		**Year 2**		**Year 3**		**Year 4**		**Year 5**	
Semester 1	*Semester 2*	*Semester 3*	*Semester 4*	*Semester 5*	*Semester 6*	*Semester 7*	*Semester 8*	*Semester 9*	*Semester 10*
20 credits	21 credits	21 credits	22 credits	22 credits	22 credits	20 credits	14 credits	19 credits	19 credits
General Sciences									
Chemical Engineering Courses									
Humanities, Arts, and Social Sciences (HACS)									
Interdisciplinary Projects (PI), Thesis, and Real Life Experiences (RLE)									
Management Courses									

Fig. 1. UTEC curricular mesh with its different transversal areas

Thus, what is meant by Chemical Engineering and what is associated with the study program should be well defined. Chemical engineering is associated with the design, construction, operation and management of industrial processes and commercial products. These products and processes have chemical, physical, biological or environmental attributes. The profession of chemical engineering is versatile and chemical engineers can be found in a large section of the professional community. Chemical engineers can work in a variety of industries, including chemical, petroleum, mining, paper, cement, plastics, pharmaceuticals, food, semiconductors, to name just a few, as well as other sectors such as research, finance and consulting. The program includes bioprocess, environmental and energy studies, as well as process systems and chemical management engineering. The degree focuses on the development of students who are industry-oriented and proficient in many aspects of personal development. With this preamble, the Program Educational Objectives of the Chemical Engineering Program relate to the mission of UTEC: Developing engineering for people and corporations of the future, via creative, social sensibility, and scientific knowledge, doing research and solving technology problems.

The academic objectives of the Chemical Engineering study program are divided into two important aspects of *general educational objectives* and *student results*. Our first general educational objective is to train future professionals to design, operate, implement, and manage processes, solutions, and procedures of Engineering, and Chemical Engineering supported by scientific and technical approaches according to sustainability principles. The second objective is to equip future professionals with critical thinking, creativity and initiative to respond in a sustainable way to the challenges of Peru and the world. And the ultimate objective is to train future professionals to act ethically and responsibly towards their environment, thus preparing them for teamwork and leadership.

In the present professional study program, students in our university are expected to:

1. Apply knowledge of mathematics, science, and engineering in solving complex engineering problems;
2. Identify, formulate, search for information, and analyze complex engineering problems to reach informed conclusions using basic principles of mathematics, natural science, and engineering science;

3. Design solutions to complex engineering problems and design systems, components, or processes to meet desired needs within realistic constraints on public health and safety, cultural, social, economic, and environmental issues;
4. Conduct studies of complex engineering problems using inquiry-based knowledge and research methods including the design and conduct of experiments, the analysis and interpretation of information, and the synthesis of information to produce valid conclusions;
5. Create, select and use modern engineering and information technology techniques, skills, resources and tools, including prediction and modeling, with an understanding of their limitations;
6. Apply informed reasoning through contextual knowledge to assess social, health, safety, legal, and cultural issues and consequent responsibilities relevant to professional engineering practice;
7. Understand and evaluate the impact of solutions to complex engineering problems in global, economic, environmental and social contexts;
8. Apply ethical principles and is committed to professional ethics and the responsibilities and standards of engineering practice;
9. Work effectively as an individual, as a member or leader of diverse teams;
10. Communicate effectively by understanding and writing reports, designing documentations, holding exhibits, and transmitting and receiving clear instructions.
11. Demonstrate knowledge and understanding of management principles in engineering and economic decision making, and their respective application;
12. Recognize the need for lifelong learning and address it in the broader context of technological change.

Previously, UTEC presented and structured its Educational Model under the three types of competences: *Transversal, General or I*+ and *Specific*. The concept of competence was born to overcome traditional education to allow learning based on knowing, knowing how to be and knowing how to train professionals under the parameters of today's world (to solve real problems).

Reflection and continuous evolution of curricula in chemical engineering are beneficial for adaptation to evolving industries and technologies and for enhancing the student experience. To this end, it was necessary to develop a method that would allow reflection on the curriculum and examine potential areas for improvement and change. The curricular structure consists of fundamental and central units of study in the former, followed by courses that make up the heart of the degree and elective subjects in the later years within the study program curriculum. Developing a curriculum that meets these changes requires thorough understanding of the current curriculum. For this reason, the Chemical Engineering Study Program at UTEC that began in 2012, has undergone periodic changes. Among the most important changes are the establishment of the name as such of Chemical Engineering, in 2015, and the last change in the study mesh in 2018. As of this date, the department has carried out educational research on student learning in the respective undergraduate program for almost three years. This research work has started from a theoretical base that sees the student as an active constructor of their own learning experience. Along with this, the following improvement opportunities were identified:

1. High loading of learning into the program, where, in some cases, there are possible environments of failure, or where students could complete their studies in a disjointed way;
2. Coherence and integration in key areas of the program, especially in mathematics, physics, teamwork, as well as written and oral communication;
3. Execution of an adequate structure and approach for the transition from college to university;
4. Selection of suitable optional subjects.

Some of the points above were partially addressed in the 2018 curriculum mesh, with the need to be rethought again, since their recurring identification indicates that they are systemic in nature. Thus, the study program aims to improve the quality of student learning by emphasizing what should be learnt to produce graduates with the appropriate engineering knowledge and who are also competent to work in a problem-based team environment. Being a broad profession, the degree of chemical engineering needs to adapt to changes in the profession and thus produce graduate students who are continually in contact with the real world.

4 Research methodology

The study employs design-based research which was commonly adopted in the development of educational products, among others curricula and educational technologies to produce a theoretical framework for future use [50][51].The curriculum revision relied on iterative processes of refinement of the situations involving various stakeholders' records of perspectives as well as field-based research by taking into account currently critical and emerging trends [52][53][54], such as Competence-Based Curriculum and 21st century skills. In this study, the competence-based curriculum matrix-based guidelines refers to the work plan specifically designed to train to guarantee an intentional learning path that would allow the formation of the current graduate profile. The work plan allows autonomy on the part of the careers and continuous learning to be able to start the process when they wish.

The revision involved the following stages: 0). Building a common language, 1). Identifying aspects that are working well at the moment and those that may need revision in the current curriculum, 2). Aligning the performance indicators using the evaluation matrix, 3). Selecting types of learning activities that correlate with Bloom's taxonomy verbs, 4). Incorporating student learning autonomy into the curriculum.

The modification of teaching-learning models in response to the new educational needs that the knowledge society demands faces obstacles such as the presence of implicit theories, habits, and deeply rooted beliefs about what knowledge is, its teaching and the conditions that can favor their learning [55]. The objective of the study is to present the methodology used to constructively align the competencies of the new 12-

degree study plans, with the specific case of Chemical Engineering study program, to achieve a current, employable, and competent graduate profile to solve real problems.

The approval to conduct the study on the exempt research category has been granted by the university research department on May 15, 2021. All identifiers in the research have also been removed.

5 Data analysis and discussion

The beginning of the process of Alignment of Competencies in the Chemical Engineering career at UTEC has been the establishment of a glossary that facilitates education staff, principals, and the rest of those involved, to establish a common language that allows the understanding of different professionals who made up the work teams during the months of January-April 2021.

The overview of the steps in aligning the competencies is described in Figure 2 and the detail will be explained in the following sections.

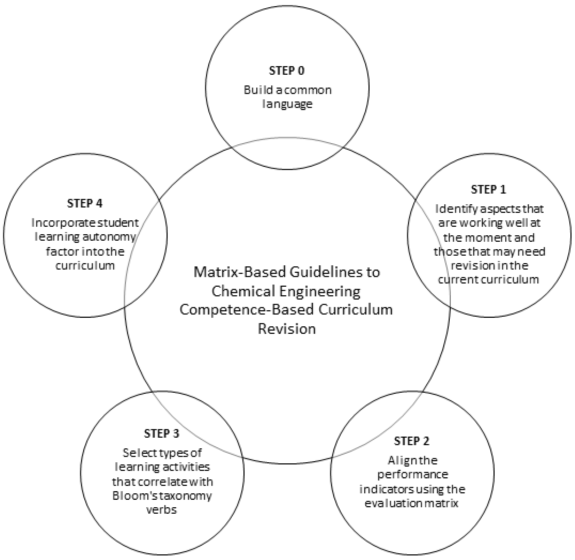

Fig. 2. Description of the steps in the curricular revision

5.1 Step 0: Building a common language

The stage of the calibration of the definition and of a model based on competencies for the study programs at the university was conducted to ensure equal viewpoint among the involved parties. Clarifying the definition and the model was the initial step to start in the process where all the faculty together with the Center of Excellence in Teaching and Learning (CE2A) area could share a common language. Relationships between different terminologies in the field of accreditation, i.e., competencies and learning outcomes were established. Competencies comprise a set of learning outcomes and are statements about what the student is expected to be able to do, understand and demonstrate once a learning process has been completed [27]. On the other hand, learning outcomes are the measurable skills and knowledge that the student acquires during the training period leading to a degree in a specific discipline [56][57][58], whether or not it is compulsory.

The concept of learning autonomy as one of the characteristics of self-directed learning [59][60] was another important aspect to review and agree among the entire educational community of UTEC. To do this, we focus on Bloom's Taxonomy and its levels that seek to ascend from lower to higher levels of learning that allow the development of the students' decision-making capacity. The students require greater accompaniment and frequent supervision by teachers, while the faculty should guarantee punctual supervision in complex or new situations. Therefore, the term *autonomy* in the study is to be understood in the light of the degree of supervision that students need in their learning process and progress. In an adequate curricular setting, the supervision of the students will be reduced as the cycle and taxonomic levels progress.

In a university with different faculties or study programs, it is essential to build a common language to move forward with curricular improvement processes and study plans. Aligning competencies here is to calibrate the relationship between accreditations and educational goals. However, we do not always find the same concepts applied in different countries and accrediting institutions. Thus, the first step was to bring together all the directors from the UTEC faculties in a meeting to clarify what is meant in the following, i.e., what competencies are, and what typologies exist in UTEC.

UTEC presents a teaching and learning model based on 3 types of competencies: General (known as I+), Transversal (those developed by all students regardless of the study programs in which they study) and Specific (those aligned with the accreditation of each discipline). To understand this process, it was necessary to create a common language to understand the alignment that must exist between the different elements mentioned above. They can be seen in the following Figure 3.

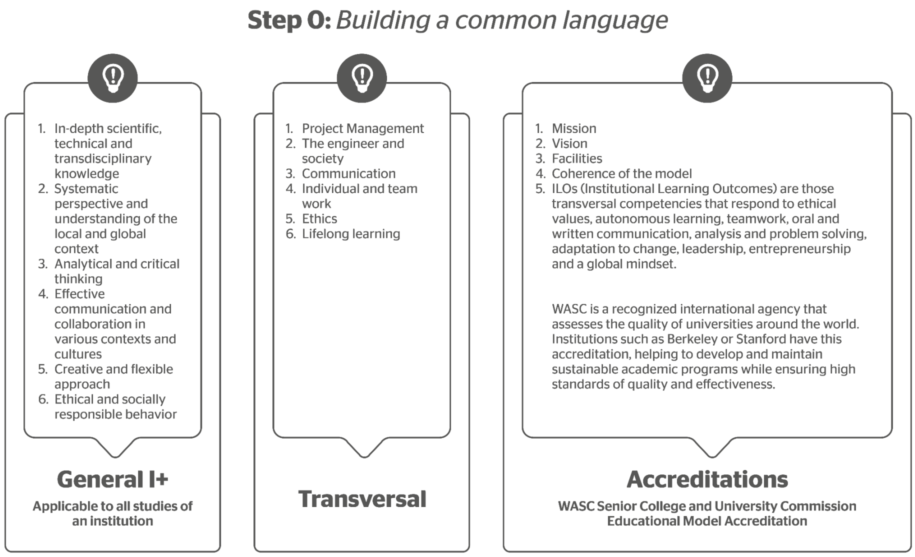

Fig. 3. Step 0: Building a common language

This stage was essential to elaborate and to attach meanings to the work of the transversal areas for better understanding of competence alignment. HACS (Humanities, Art and Social Sciences), Sciences, Management, and Projects contribute to the training of UTEC professionals within accreditation systems that are not typical of their disciplines. This understanding and joint work adds value to the study plans.

5.2 Step 1: Identify aspects that are working well now and those that may need revision in the current curriculum

During the 2018 curriculum implementation, each faculty noticed some opportunities for improvement in the evolution of the competencies corresponding to the courses. This was according to the progress of the curriculum from the point of view of integration and the balance of the academic load based on the credits assigned to each course per semester. This identification was carried out in periodic departmental meetings. With this background, the inclusion of an additional component to the planning of student work hours outside the classroom was considered in each course and assigned as autonomous work. The planning of the autonomous work to be included as a component in the curriculum is associated with the assignments indicated by the instructor according to Bloom's taxonomy, the number of credits and the student's results. For example, *Introduction to Chemical Engineering* is a first year course with one-hour theory and two-hour laboratory respectively. The autonomous work is set to maximum two hours per theory hour and one hour for practical credit, thus the mentioned course counts as 4 hours of autonomous work.

During this phase, all the necessary inputs were prepared to be able to carry out the pertinent diagnosis and guide the curricular update and skills required in each career.

The aspects that were reviewed from the curriculum prior to the CBC curriculum were the need to track whether the levels of competencies were presented in a progressive sequence of learning from lower levels to higher levels of knowledge and autonomy in each of its courses. The need for structuring the association of student assessments was conducted in compliance with Bloom's taxonomy. Some of the types of competences were shared with other study programs at the university so these competences could be grouped in transversal courses.

5.3 Step 2: Align the learning outcomes using the evaluation mapping

In this second step, the curriculum alignment process was further conducted to ensure coherence and consistency of the intended outcomes as stated in the formal curriculum, teaching methods, assessment tasks, and classroom learning activities [61]. In the alignment process, one of the key inputs was the competency matrix mapping exclusively developed by the UTEC Center of Excellence in Teaching and Learning for this project. The matrix, accompanied by the definition of 5-year curricular criteria and their taxonomic levels in agreement with the learning outcomes from the accrediting institutions, helped to organize and standardize the work of aligning skills in each study program, one of which was Chemical Engineering Department. Table 1 shows a comparison of the learning outcomes of ICACIT and ABET, and UTEC elements of I+. ABET and ICACIT are the accreditors that the university chose to accredit the Chemical Engineering study program because these two accrediting agencies are the largest ones in Latin America. The study program was accredited by ICACIT in 2018. Meanwhile, ABET accreditation is UTEC's near future goal as the second recognition of educational quality in the discipline.

Each accreditor employs a different language in dealing with accreditation. For this reason, and referring to the need to create a common language, Table 1 was created. In this way, the faculty could understand the relationship between the competencies of ABET, ICACIT and those of UTEC, as well as the differences between them. This understanding helps to establish an optimal work process that assumes the three competency edges and their interrelationships.

Generic competences are chosen by a university as an educational institution, in accordance with its educational model. At UTEC they are called I+ and developed in interaction with the specific competencies of each study program.

At UTEC, all graduates should demonstrate the achievement of the following six general competencies or I + since the inclusion of general competencies signifies the hallmark of every university.

1. Deep scientific, technical, and transdisciplinary knowledge.
2. Systemic perspective and understanding of the local and global context.
3. Analytical reasoning and critical thinking.
4. Effective communication and collaboration in diverse contexts and cultures.
5. Creative and flexible approach.
6. Ethical and socially responsible conduct.

Table 1. A comparison of learning outcomes of ICACIT and ABET, and elements of UTEC I+

ICACIT [62][63]		**ABET [64]**	**UTEC [65]**
Learning outcomes		***Learning outcomes***	***I+ (Ingeniería or Engineering Plus)*** – Elements included in UTEC vision as drawn from ICACIT and ABET
RE-I01 Knowledge in Engineering	Applying knowledge of mathematics, science, and engineering in solving complex engineering problems.	The ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics	In-depth scientific, technical, and transdisciplinary knowledge
RE-I02 Problem Analysis	Identifying, formulating, searching for information, and analyzing complex engineering problems to reach well-founded conclusions using basic principles of mathematics, natural science, and engineering	The ability to identify, formulate, and solve complex engineering problems by applying engineering, scientific, and mathematical principles	Analytical and critical thinking
RE-I03 Design and Development of Solutions	Designing solutions to complex engineering problems and designing systems, components, or processes to meet needs within realistic public health and safety, cultural, social, economic, and environmental constraints	The ability to apply engineering design to develop solutions that meet specific needs considering public health, safety, and welfare, as well as global, cultural, social, environmental and economic factors	
RE-I04 Research	Leading studies of complex engineering problems using inquiry-based knowledge and research methods, including designing and conducting experiments, analyzing and interpreting information, as well as synthesizing information to reach valid conclusions	The ability to develop and conduct appropriate testing, to analyze and interpret data, and to use engineering judgment to draw conclusions	Analytical and critical thinking
RE-I05 Use of Modern Tools of Engineering	Creating, selecting, and using modern engineering and information technology techniques, skills, resources and tools, including prediction and modeling, while understanding their limitations.	The ability to identify, formulate, and solve complex engineering problems by applying engineering, scientific, and mathematical principles	
RE-I06 Engineering and Society	Applying informed judgments through contextual knowledge to evaluate social, health, safety, legal and cultural issues and the resulting responsibilities pertinent to the professional practice of engineering	The ability to recognize ethical and professional responsibilities in engineering situations and to make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and social contexts	Systematic perspective and understanding of the local and global context

RE-I07 Environmental Sustainability	Understanding and evaluating the impact of solutions to complex engineering problems in a global, economic, environmental and social context	The ability to recognize ethical and professional responsibilities in engineering situations and to make informed judgments, which must consider the impact of engineering solutions in global, economics, environmental, and social contexts	Ethical and socially responsible behavior
RE-I08 Ethics	Applying ethical principles and committing to professional ethics and engineering standards and responsibilities	The ability to recognize ethical and professional responsibilities in engineering situations and to make informed judgments, which must consider the impact of engineering solutions in global, economics, environmental, and social contexts	Ethical and socially responsible behavior
RE-I09 Individual and Team Work	Effectively functioning as an individual, a member or a leader of various teams	The ability to function effectively in a team whose members provide leadership, create a collaborative and inclusive environment, set goals, plan tasks, and accomplish objectives	Effective communication and collaboration in various contexts and cultures
RE-I10 Communication	Communicating effectively, by understanding and writing reports and layout documentation, making presentations, and conveying and receiving clear instructions	The ability to communicate effectively with diverse audiences	Effective communication and collaboration in various contexts and cultures
RE-I11 Project Management	Demonstrating knowledge and understanding principles of engineering management and economic decision making, and their corresponding application	The ability to recognize ethical and professional responsibilities in engineering situations and to make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and social contexts The ability to function effectively in a team whose members provide leadership, create a collaborative and inclusive environment, set goals, plan tasks, and accomplish objectives	In-depth scientific, technical, and transdisciplinary knowledge
RE-I12 Lifelong Learning	Recognizing the need for lifelong learning and addressing it in the broadest context of technological change	The ability to acquire and apply new knowledge as needed, using appropriate learning strategies	Systematic perspective and understanding of the local and global context

The contents of the courses were revised to avoid the repetition of contents between courses that are close in terms of topics or disciplines. Before alignment of the competencies was adopted, the contents of the courses should be revised. The Department worked on contrasting the contents using the following categorization criteria to guarantee balanced courses in terms of the coverage of topics.

First, the core topics of each course were taken into consideration, specifically what students must know to function professionally in each discipline. Second, the complementary topics were included since the contents should be learnt by the students in the courses within the later semesters. Ultimately, supplementary topics were parts of the study program as well; however, they were not being assessed. Possibly, the supplementary topics are to be expanded in the courses of later semesters.

After the content organization and classification, the following task was the alignment of competencies in agreement to the graduate profile. To understand this process for the competencies distribution in the new 2021 curriculum, it is necessary to analyze the criteria that UTEC must follow. The work team, consisting of professors and CE2A, must consider the following criteria for competencies addressed in each course and their distribution in all the curriculum. One of the distributions is observable in the consideration that a competency can only have one level. If a competency can consist of several taxonomic levels during one semester, the highest level should be selected. All competencies must be developed in at least one course and each course will develop 3-4 competencies. One course in the Chemical Engineering Department — *Introduction to Chemical Engineering* could include transversal, general and specific competencies at level 1.

All the competencies must be linked to the evaluation system of each course to be able to evidence their mentioned concession or development (see Table 2). In this way, we ensure that students who pass the course should develop the indicated competencies. With the objective to monitor the competences developed by students, UTEC proposes the following 3 divisions alongside the progress within the studies linked to performance levels that facilitate the monitoring of the student's competencies and their development (see Table 2):

- The 1st division (from first to third semester): to develop levels 1 and 2 of the competencies.
- The 2nd division (from fourth to seventh cycle): to develop levels 2 and 3.
- The 3rd division (from eighth to tenth cycle): to develop level 3.

Table 2. The levels of competencies applied at UTEC drawn from the three competency levels described (based on Bloom's taxonomy concept)

ICACIT	UTEC I+	Examples of Activities and Evaluation System Linked to Bloom's Verbs
Level 1		
The student performs the competency with the help and constant supervision of an expert. The learner is aware of his/her limitations and his/her choices must be validated.	*To remember:* The student remembers and memorizes the information, without necessarily understanding it. *To comprehend:* The student understands the information and explains the relationships of the whole and its parts.	*To comprehend:* - how to develop a presentation - how to write a blog post - how to write an article for a conference - how to write a report
Level 2		
The learner performs the competency under the periodic supervision of an expert, but with help in case of new	*To apply:* The student uses what has been learned in new situations, i.e., solves problems by handling the ideas and concepts learned.	*To analyze:* - Text commentary and analysis - Reviews of:

situations, so he/she must validate his/her choices but is able to discern nuances or ramifications.	*To analyze:* The student is able to distinguish and separate the information learned into its principles or elements, looking for interrelationships.	• Commentary on a news item or article • Evaluation of a scientific text. • Elaborate conclusions.
	Level 3	
The learner performs the competency unaided and unsupervised. His/her actions do not require supervision (only light supervision in unusual situations). The learner can exercise initiative in complex or high-risk situations and is able to predict the impact of his or her decisions.	*To evaluate:* The learner can make judgments by estimating, appreciating, and calculating the value of something. *To create:* The learner can create something new by adding up and compiling parts and analyzing them.	*To evaluate:* - Analysis or assessment of final products based on rubrics or evaluation criteria - Argued reflections

Another point to consider is that when developing the matrix of competencies and levels, it was intended to show a balance in the distribution of their occurrences in the undergraduate cycles. All learning outcomes were referred to at different levels and were developed in the training courses in the Chemical Engineering curriculum (see Figure 4). The weighted sum of learning outcomes at the different levels is as follows: level 1, 54; level 2, 85; level 3, 56. This shows a greater incidence of the 2nd level developed in the courses within semesters 4 through 7. Figure 4 below shows the distribution of the learning outcomes. It also shows a greater emphasis on the development of learning outcomes 10.1, 10.2, 10.3 (students apply knowledge of mathematics, science and engineering in the solution of complex engineering problems), 10.1 (students communicate effectively orally by giving presentations and transmitting and receiving clear instructions) and 5.1 (students create, select, and use modern engineering and information technology techniques, skills, resources and tools, including prediction and modeling, with understanding of its limitations).

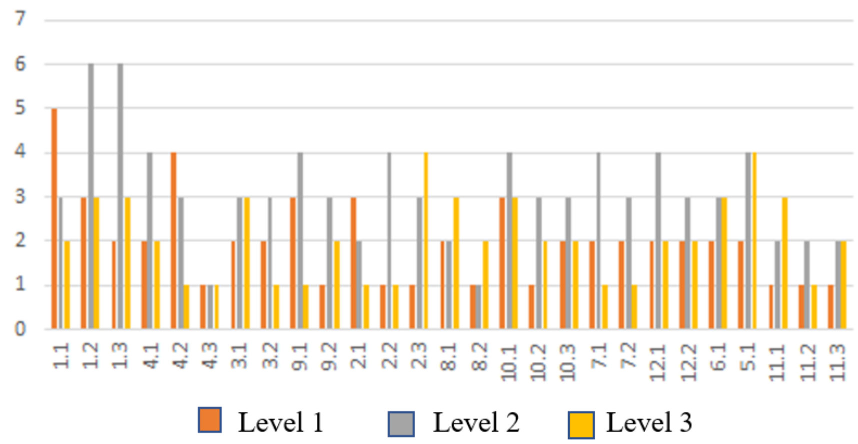

Fig. 4. Distribution of learning outcomes

5.4 Step 3: Select types of learning activities that correlate with Bloom's taxonomy verbs

In this phase, once the competencies of each subject or course had been aligned, the most appropriate activities were selected to propose the measurement of each of the competencies at the level indicated within each course. The alignment here refers to whether the acquisition of the respective competencies has been done in accordance with the principles of Bloom's taxonomy. The alignment here guarantees a learning path based on gradual competencies, from the lower levels of learning to those that are more autonomous, according to Bloom's taxonomy.

A sample of Bloom's verbs (see Figure 5) and the activities proposed in some Chemical Engineering courses (see Table 3) are elaborated in the following.

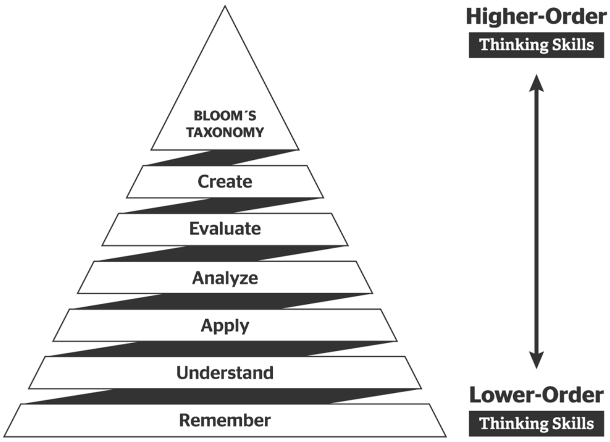

Fig. 5. Bloom's taxonomy verbs

In Table 3, we can observe an association between the verbs of Bloom's learning levels and the activities assigned in each course of the curriculum.

Table 3. Bloom's taxonomy verbs and activities

Taxonomy Levels	Related Verbs (Contextualized within Chemical Engineering Study Program)	Activities
Remember	• Identify (Chemical Analysis for Engineering, Chemical Process Analysis) • Describe (Chemical Analysis for Engineering) (Chemical Processes in Industry) • Recognize (Advanced Chemistry) • Review (Applied Organic Chemistry) • Classify (Chemical Process Analysis)	• The student identifies and compares the information from literature and the cases presented in classes. • The student reviews and analyzes information such as laboratory guides to recognize specific potential risks and hazards in process diagrams. • The student classifies relevant information useful for material and energy balance, and analyzes the results.

Understand	• Explain concepts (Biotechnology and Bioprocesses, Chemical Analysis for Engineering, Chemical Process Analysis, Chemical Processes in Industry) • Distinguish (Chemical Processes in Industry, Applied Organic Chemistry) • Relate (Advanced Chemistry), • Define (Chemical Process Analysis)	• The student explains concepts through the preparation of a design project about a chemical process or bioprocess, and integrates the knowledge learnt. • The student communicates in writing reports the objectives achieved in their laboratory experiences and associates them with their results, discussion, and conclusions. • The student defines alternative solutions for engineering problems with tools such as spreadsheets and/or process simulators.
Apply	• Calculate costs (Chemical Process Design), • Calculate kinetics (Transport Phenomena), • Resolve (Mass Transfer), • Apply principles (Separation Operations I) • Calculate (Separation Operation II) • Apply (Mass transfer, Heat Transfer), • Convert (Chemical reactor design I), • Elaborate (Transport Phenomena), • Label (Separation operation I), • Use (tables, strategies, diagrams, data) (Transport Phenomena), • Tabulate (Separation operation II), • Formulate (Control of chemical processes), • Execute skills, modern tools, and resources (Chemical reactor design I)	• The student calculates the costs and the economic evaluation associated with the selected chemical processes using key economic indicators. • The student calculates kinetic data in the design of a final project of the semester with predefined performance specifications. • The student solves problems based on experimental information from literature or laboratory. • The student applies engineering tools skillfully such as simulators for the design of unit operations of separation. • The student calculates using autonomous and precise phenomenological models of processes relevant to chemical engineering. • The student elaborates conceptual designs of selected processes. • The student classifies models of process systems through the development of selected cases. • The student uses tables, block diagrams, phenomenological models to develop case studies. • The student tabulates and classifies information obtained in laboratories to analyze separation processes (unit operations). • The student formulates control strategies through the solution of case studies extracted from the chemical process industry. • The student executes skillful engineering tools such as Matlab, Promax and other simulation software to solve selected problems and case studies.
Analyze	• Discuss (Chemical engineering seminar) • Resolve engineering problems (Separation operations I) • Simplify (Fluid mechanics), • Differentiate (Transport Phenomena) • Analyze (Control of chemical processes) • Distinguish (Transport Phenomena) • Order or systematize teamwork (Process safety engineering)	• The student discusses sustainability criteria and economic engineering concepts applied to chemical processes projects. • The student solves engineering problems to learn relevant theoretical concepts. • The student analyzes separation operations (chemically and physicochemically) to implement control strategies through selected cases. • The student distinguishes different transport phenomena in the development of selected specific cases. • The student systematizes the teamwork of a group project to determine the safety of chemical processes.

Evaluate	• Evaluate forms of communication (Thesis II)	• The student evaluates forms of oral and written communication in the presentation of the thesis milestones. • The student communicates the results using tables, comparative graphs, and figures. • The student designs with relative autonomy and precision a chemical process, through a project, using spreadsheets, programming languages and simulators, when necessary. • The student dimensions capacities and equipment and selects the control instruments, applying concepts of instrumentation and control of selected chemical processes in a teamwork. • The student integrates knowledge from the different subjects learnt in the 5 years of study to generate results in their thesis research.
Create	• Design (Chemical Process Design) • Calculate the dimension (Chemical Reactor Design I, Control of Chemical Processes) • Integrate (Thesis II) • Create resources, skills (Thesis II)	• The student evaluates forms of oral and written communication in the presentation of each advance of the thesis project. • The student communicates through tables, comparative graphs, figures, showing the results obtained. • The student designs with relative autonomy and precision a chemical process, through a project, using spreadsheets, programming languages and simulators, when necessary. • The student calculates dimensions, selects control instruments, applying concepts of instrumentation and control of selected chemical processes through group work. • The student integrates knowledge from different subjects taught within the 5 years of study to generate the desired results in thesis research work, presenting each progress.

Figure 6 shows a conceptual map with the criteria and guidelines applied for the implementation of the previously presented information that resulted in the new Chemical Engineering curriculum, as well as the establishment of indicators for monitoring the process of addressing competencies and expected learning outcomes.

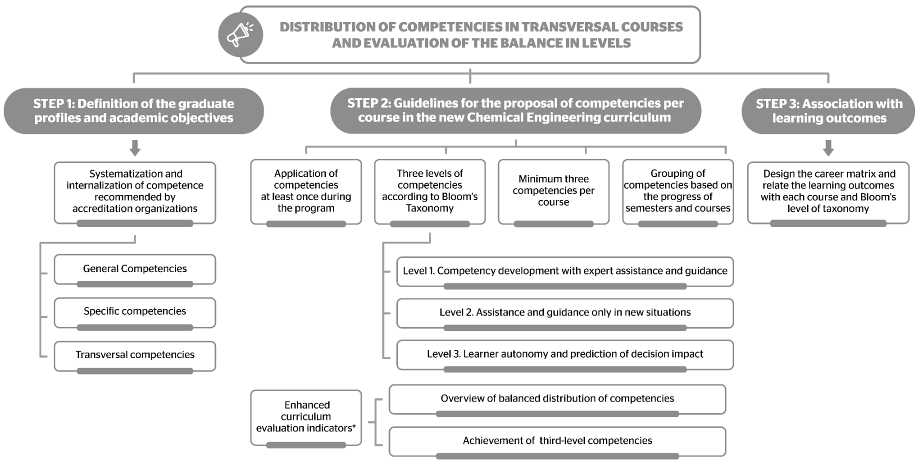

Fig. 6. Methodology for the definition and analysis of competences and learning outcomes

Meanwhile, the interconnections between learning outcomes, three types of courses in the curriculum, and their distributions throughout different semesters are illustrated in the following Figure 7.

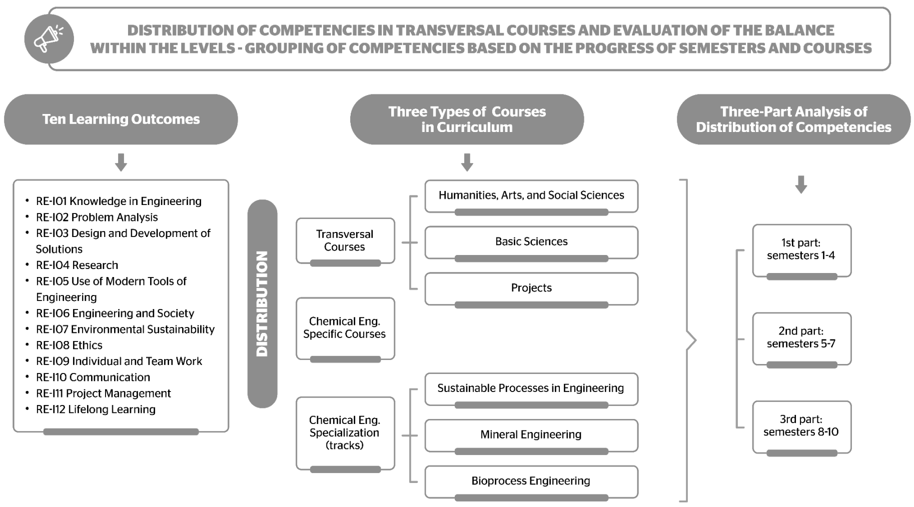

Fig. 7. Progressive distribution and grouping of learning outcomes by semesters and types of courses in the Chemical Engineering curriculum

Related to the selection of types of learning activities, assessment is another area that should be calibrated within the new curriculum. Authentic assessment is a concept recently introduced at UTEC to improve and guide students in the teaching and learning process. The objective of authentic assessment is to assess the achievement of the meaningful real-world learning outcomes and of the tasks that are based on real-world practice [66]. The respective type of assessment uses various procedures and techniques in a defined context where the teaching-learning process occurs to validate the standardization of the assessment and the evaluation that was conducted with the participation of the UTEC faculty. The faculty also established the types of activities that occurred during the course among which are exams, supported readings, and laboratory reports (see Figure 8).

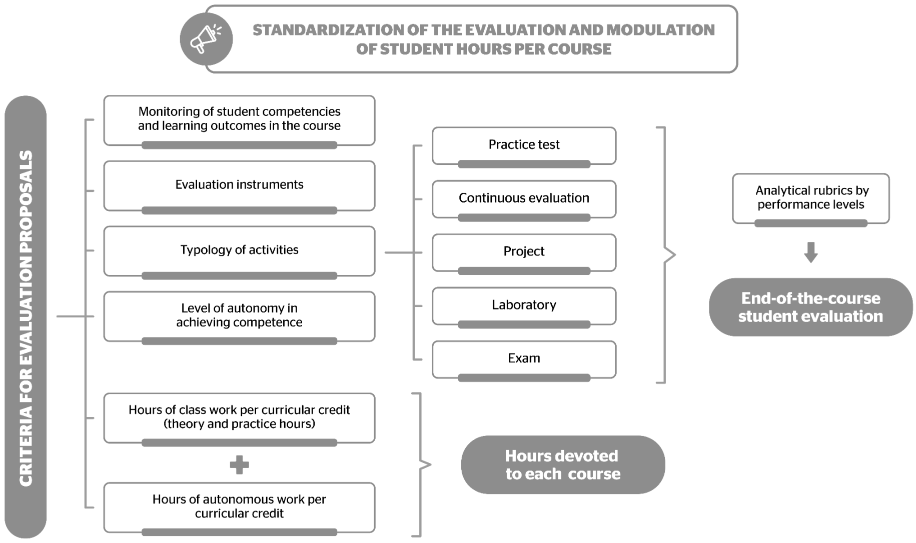

Fig. 8. Standardization of the evaluation and modulation of the student's time dedication

Taking the standardization of the evaluation of the 2021 curriculum into consideration is necessary to understand the following assumptions:

a) The evaluation at UTEC has five categories of activities with the nomenclatures of Continuous Evaluation (C), Project (P), Laboratory (L), Exam (E) and Qualified Practice (PC) found in the syllabus of each course.
b) The evaluation system and nomenclature established in the syllabus of each course must be the same as that reflected in educational platforms.
c) The different types of evaluation activities must be aligned to the course competencies.
d) The type of evaluations must correlate with the number of activities according to the credit value described in Figure 8.

5.5 Step 4: Incorporate student learning autonomy factor into the curriculum

The objective of this phase was to balance the workload based on the value of the credit and the execution time of each of the tasks or activities that can be evaluated in each course. The value of the teaching hour in Peru is defined by SUNEDU (Spanish initials of National Superintendence of Higher Education) following the logic within 2 cycles or semesters of 16 weeks' duration respectively (see Table 4):

Table 4. Number of credit in comparison to hour of teaching

Type of credits	Number of teaching hours
One theoretical credit	One hour of teaching
One practical credit	Two hours of teaching

The teaching time is understood as "direct instruction" in the presence. The practical credit in universities is to be referred to as a laboratory. In contrast, the concept of non-teaching hours defines the autonomous work time that the student needs to complete their learning path in a complementary way to direct instruction. From this point of view, to balance the "load" of the student, it is necessary for both types of hours to be balanced in a curricular mesh. In Peru, this decision is forged within the autonomy of the university. In the case of UTEC, it is calculated as elaborated in Table 5:

Table 5. Number of credit in comparison to hour of teaching and hour of no teaching

Number of credit	Hour of teaching	Hour of no teaching
One theoretical credit	One hour of teaching weekly	Maximum two hours of no teaching or autonomous work
One practical credit	Two hours of teaching weekly	Maximum one hour of no teaching or autonomous work

All these formulas allow us to balance continuous evaluations and tasks so as not to exceed the time stipulated in a study grid. There are different examples in the world of the benefits of this type of work. ECTS in Europe with its Bologna Plan is probably the best known and referenced in this regard [67][68].

Finally, all sections or phases were evaluated to guarantee the coherence of the study plan or curriculum that the institution hopes to achieve. It is a phase of review, quality validation and adjustment. The final courses of the UTEC study programs such as the final degree projects (Thesis 1 and Thesis 2) or the professional practice courses (Real Life Experience) denote the closure of a greater number of competencies than the rest of the regular courses and at higher levels. This makes it possible to holistically "conclude" what was learned during the 5-year study program. Aligning competencies in university education models is synonymous with reflection and continuous improvement in the face of accelerated social, technological, and educational changes.

6 Conclusion and lessons learned

A 150-day process of implementation of new competence-based curriculum matrix-based guidelines was presented. A curriculum restructure relies on pragmatic and iterative refinement of the situations integrating various stakeholders' perspectives as well as field-based research by considering currently critical and emerging trends, such as the inclusion of the 21st century skills, competence-based curricular pedagogy, and active and lifelong learning.

This process showed strengths such as prompt communication between stakeholders to coordinate and resolve doubts and give meaning to the work of the transversal areas in this understanding of competence alignment. Departments of Humanities, Arts, and Social Science; Science; Management; and Interdisciplinary Projects contribute to the training of UTEC professionals within accreditation systems that are not typical of their specific disciplines. Therefore, this understanding and joint work is essential to add value in the study plans.

The matrix-based guideline is a work in progress and there is no doubt that a dynamic environment will always be the base for our decision making. Future research could focus on the implementation of this model in South American universities or beyond, possibly with some necessary modifications taking into account the national accrediting boards.

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8 Conflict of interest statement

The authors declare that there is no conflict of interest.

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