ENGINEERING PROFILE DEFINITION BASED ON THE CDIO MODEL

María Hilda Flores, Evelyn Melo, Alejandro Morales

Metallurgical and Mining Engineering Department, Universidad Católica del Norte, Chile

Isabel Yel

Quality Management of Engineering Faculty, Universidad Católica del Norte, Chile

ABSTRACT

The present study describes a methodology based on the CDIO model to re-design Universidad Católica del Norte (UCN) engineer profiles. UCN will re-design the engineering curriculum supported by a Chilean government grant, this being the first stage of the project. The profile definition process began with a survey of all stakeholders (faculty members, graduates, and employers). The conclusions of the survey analysis provided the skill level of proficiency and the attitudes at X.X level described in the Syllabus CDIO. These were then validated using Bloom's taxonomy to determine learning outcomes. The latter were compared with other requirements such as ABET criteria (criterion 3), Tuning competences, and UCN Educational Project. Finally, the UCN engineer profile was defined based on the learning outcomes associated with knowledge, attitudes, and skills described in the CDIO Syllabus. The UCN engineer profile was validated in a workshop with the chiefs of engineering programs and a CDIO expert. The UCN engineer profile is the framework to build the specific profiles for engineering programs.

KEYWORDS

Engineering profiles, CDIO Syllabus, learning outcomes, CDIO Standard 2.

INTRODUCTION

This paper describes the process for defining the UCN engineer profile, using CDIO methodology. CDIO Standard 2 states that knowledge, skills, and attitudes resulting from engineering training, i.e., learning outcomes, must fully describe what students should know and be able to do after graduating from an engineering program. Apart from learning results connected to technical and disciplinary knowledge, the CDIO syllabus clearly describes learning outcomes associated with personal and interpersonal skills and also product, process, and systems construction skills.

UCN is redesigning its engineering programs, supported by a grant from the Chilean government (UCN 1204 "Reinventing Engineering"), this being the first stage to attain the goal of the project: "to train engineers who effectively respond to 21st century demands, strengthening UCN technical and organizational capabilities through a thorough reform including curriculum, learning methodologies, admission system, and student promotion".

Other experiences in Chile have used the CDIO methodology for designing the curriculum of some engineering programs. (Poblete, P. "et al", Loyer, S, "et al")

UCN conducted a study based on an MIT methodology to identify undergraduate competences, knowledge, and skills for all its engineering programs. This methodology contributed to the reformulation of the educational concept of engineering so as to improve the way these skills are taught and learned. The result of this study, called “CDIO Syllabus”, aims to include the knowledge, skills, and attitudes that students, industry, and faculty members expect from future engineers.

Knowledge was determined by means of an analysis conducted by faculty members from each engineering program (Redesign Board) and the support of a CDIO methodology expert.

Skills and attitudes were determined via the analysis of a questionnaire administered to groups of interest (faculty members, graduates, and employers)

The profile is based on learning results associated with technical and disciplinary knowledge, personal and interpersonal skills, and the construction of products, processes, and systems determined by the CDIO Syllabus, which will be the reference framework for redesigning the specific profiles of UCN engineering programs.

In addition, special attention was put on the determination of learning outcomes; particularly on ABET criteria (criterion 3), Tuning competences, and UCN Educational Project requirements. These requirements are shown in the Annex.

The process to formulate the UCN Civil Engineer Profile is described below:

1. Analysis of the questionnaire administered to stakeholders (faculty members, graduates, and employers)
2. Determination of learning outcomes
3. Comparison with other requirements
4. Definition of the UCN Civil Engineer Profile

Analysis of a questionnaire administered to stakeholders (faculty members, graduates, and employers)

The database consisted of 1162 graduates, 272 employers, and 89 faculty members. The response percent amounted to 9.91% graduates, 12.81% employers, and 42.86% faculty members. Only 47.22% employers have hired a UCN engineer; thus, the total number of responses decreased from 36 to 17.
The survey is based on two types of scales. Table 1 assigns the proper level of competency in each Syllabus component at level X.X, as shown below. The skills and attitudes evaluated are shown in Table 2.

Table 1. Survey evaluation scale.

1	2	3	4	5
To have experience or been exposed	To Be able to understand and explain	To be able to participate and contribute	To be skilled in the practice or implementation	To be able to lead or innovate

In the second part of the survey, the respondent assigns a low (-) or high (+) value to sub-topics X.X.X described in the Syllabus CDIO, depending on his/her estimation of the less or greater importance, as compared to those of section X.X. (Edward F. Crawley, 2001)

Table 2: Classification of skills and attitudes at level X.X

ITEM X.X	CONCEPT	ÍTEM X.X	CONCEPT
2.1	Engineering reasoning and problem solving	4.1	External and societal context
2.2	Experimentation and knowledge discovery	4.2	Enterprise and business context
2.3	System thinking	4.3	Conceive and engineering systems
2.4	Personal skills and attitudes	4.4	Designing
2.5	Professional skills and attitudes	4.5	Implementing
3.1	Multi-disciplinary Teamwork	4.6	Operating
3.2	Communications	4.7	Leading engineering endeavors
3.3	Communications in foreign language	4.8	Entrepreneurship

Within general competences at levels 2.1 and 4.8 shown in Table , ***"Personal skills and attitudes"*** (2.4), ***"Professional skills and attitudes (Ethics, equity, and other responsibilities)"*** (2.5), ***" Multidiciplinary Team work"*** (3.1), ***"Communication"*** (3.2) and ***"Leading engineering endeavors"*** (4.7) on average were rated higher than 4. This result is quite amazing because these topics are not technical, but rather personal and interpersonal. This is shown in Figure 1, H indicating a high level of evaluation for level XX competences.

In addition, "Experimentation and knowledge discovery" (2.2), "External, societal, context" (4.1), and "Implementing" (4.5) are less important. These categories were rated higher than 3, being the lowest in the group of competences. Similarly, in figure 1, L indicates a low level in total evaluation, values ranging from 2.5 to 3.5. This allows characterizing this group in option 3 when evaluating section 1, i.e., as "Be able to participate and contribute", focusing on the fact that engineers must actively engage in this type of competency.

In addition, the other concepts were rated from 3.5 to 4.5, thus being categorized in evaluation option 3 in section 2, as “Be highly skilled in practice or implementation”, associated with the fact that engineers must be more experienced in these competences.

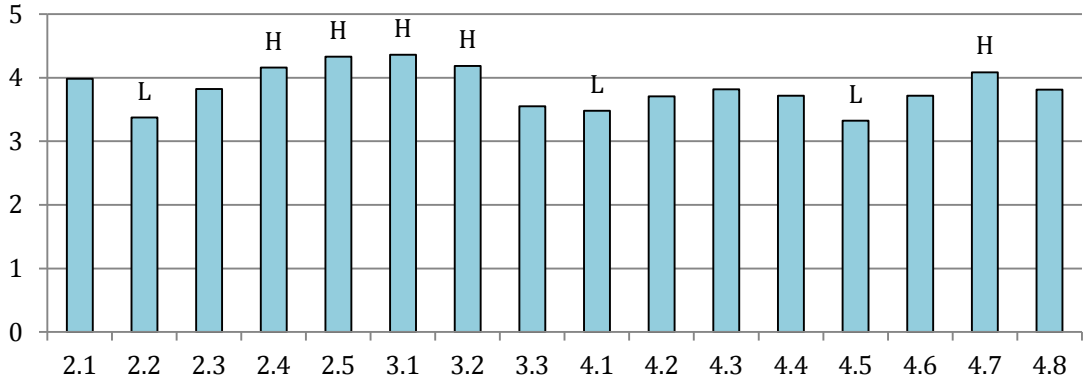

Figure 1: Average evaluation for all groups

Source: Elaborated by the author

The analysis of results shows that all competences were rated over 3.0 at level 3, i.e., a minimum level of “Be able to participate and contribute”. For this reason, it is essential to include all the CDIO Syllabus skills and attitudes at level XX in the UCN Engineer Profile.

Furthermore Figure 2 shows the results obtained by stakeholder.

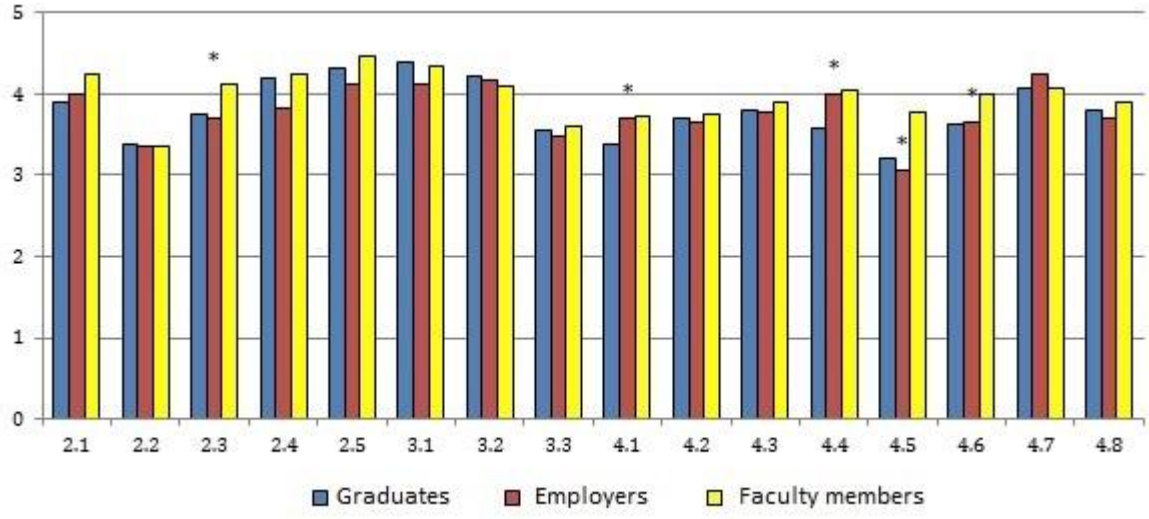

Figure 2: Evaluation obtained by stakeholder.

Source: Elaborated by the author

Definition of learning outcomes

To determine learning outcomes, the competences from the UCN Educational Project and the most significant evaluation (positive in group evaluation) of the questionnaire results at level X.X.X were considered. This is shown in Table 3.

Table 3. Classification of skills and attitudes at level X.X.X

ITEM	Level X.X	ITEM	Highest evaluation at level X.X.X	Provisional evaluation X.X.X
2.1	Engineering reasoning and problem solving	2.1.1	Problem identification and formulation	4.290
		2.1.5	Solution and recommendations	4.080
		2.1.3	Estimation and quantitative analysis	4.000
2.2	Experimentation and knowledge discovery	2.2.1	Hypothesis formulation	3.653
		2.2.4	Hypothesis test and defense	3.472
2.3	System thinking	2.3.1	Thinking Holistically	3.881
		2.3.3	Prioritization and focus	4.000
2.4	Personal skills and attitudes	2.4.1	Initiative and the willingness to make decisions in the face of uncertainly	4.313
		2.4.2	Perseverance, Urgency, and will to deliver, resourcefulness and flexibility	4.313
		2.4.3	Creative thinking	4.347
		2.4.4	Critical thinking	4.239
		2.4.7	Time and resource management	4.273
2.5	Professional skills and attitudes	2.5.1	Ethics, integrity, and social responsibility	4.727
		2.5.2	Professional behavior	4.574
		2.5.4	Staying current on the world of engineering	4.227
		2.5.6	Trust and loyalty	4.511
3.1	Multi-disciplinary Teamwork	3.1.1	Forming effective teams	4.447
		3.1.4	Team leadership	4.739
		3.1.5	Technical and multidisciplinary teaming	4.420
3.2	Communications	3.2.1	Communication strategy	4.239
		3.2.3	Written communication	4.295
		3.2.6	Oral presentations	4.381
		3.2.7	Inquire, listen, dialog	4.415

		3.2.8	Negotiation, compromise and conflict resolution	4.563
		3.2.9	Advocacy	4.250
3.3	Communications in a foreign language	3.3.1	Communication in English	4.420
4.1	External and societal context	4.1.1	Roles and responsibility of Engineers	3.653
		4.1.2	The impact of engineering on society and the environment	3.670
		4.1.6	Developing a global perspective	3.511
		4.1.7	Sustainability and the need for sustainable development	3.920
4.2	Enterprise and business context	4.2.2	Enterprise stakeholders, strategies, and goals	3.989
		4.2.6	New technology development and assessment	3.858
		4.2.7	Engineering project finance and economics	3.886
4.3	Conceive and engineering systems	4.3.1	Understanding needs and setting goals	4.176
		4.3.4	Project development management	3.948
4.4	Designing	4.4.2	The design process: phasing and approaches	3.739
		4.4.3	Utilization of knowledge in design	3.722
		4.4.5	Multidisciplinary design	3.966
		4.4.6	Design for sustainability, safety, aesthetics, and operability	3.949
4.5	Implementing	4.5.1	Designing a sustainable implementation process	3.670
		4.5.5	Test, verification, validation, and certification	3.381
		4.5.6	Implementation management	3.585
4.6	Operating	4.6.1	Design and optimize sustainable and safe operations	4.023
		4.6.4	Systems improvement and evolution	3.773
		4.6.6	Operational management	3.960
4.7	Leading engineering endeavors	4.7.1	Identifying the issue, problem or paradox	4.256
		4.7.2	Thinking creatively and communicating possibilities	4.165
		4.7.3	Defining the solution	4.142
		4.7.6	Planning and managing a project	4.318

			to completion	
		4.7.8	Innovation-the conception, design and introduction of new goods and services	4.068
		4.7.10	Implementation and operation, the creation and operation of the goods and service that deliver value	4.193
4.8	Entrepreneurship	4.8.1	Company founding, formulation leadership and organization	4.011
		4.8.2	Business plan development	4.057
		4.8.5	Conceive products and services around new technology	3.960
		4.8.7	Building the team and initiating engineering processes	3.881

The following skills and/or attitudes from UCN Educational Project were considered, despite they were rated 0:

- Continuous learning
- Equity, justice, and personal development.

Learning outcomes were written according to Bloom's taxonomy, in the corresponding scale.

The engineer profile must reflect the highest development levels of skills and attitudes (provisional evaluation), i.e.:

- Team leadership (4.739)
- Ethics, integrity, and social responsibility (4.727)
- Professional behavior (4.574)
- Negotiation, compromise and conflict resolution (4.563)
- Trust and loyalty (4.511)

Comparison with other requirements

Comparisons were made between learning outcomes and other requirements such as ABET criteria (criterion 3), Tuning competences, and UCN Educational Project. The objective of this comparison is that the profile prudential criteria incorporate international accreditation and facilitate student mobility.

Definition of the UCN Engineer Profile

A UCN Engineer Profile proposal was made, based on learning outcomes associated with knowledge, skills, and attitudes.

The UCN engineer profile was validated in a workshop with the chiefs of engineering programs and a CDIO expert. Opinions given and observations made by the audience were also considered. In addition, the procedure to define the engineer profile of each discipline was established. Moreover, the following skills were considered important and, thus, were added to the profile:

- Modelling
- Experimental research
- Graphic communication

RESULTS

General description of the UCN scientific-based engineer profile.

The general description of the UCN scientific-based engineer profile consists of three paragraphs. The first one deals with issues established in the UCN Educational Project, which gives origin to the UCN engineer seal; the second paragraph puts emphasis on the main competences a UCN civil engineer must develop; and the third one refers to the disciplinary seal based on the CDIO model (conceive, design, implement, and operate). The profile is stated below.

Graduation profile of the UCN scientific-based engineer

The UCN engineer is a comprehensive and innovative professional, characterized by ethical principles, a deep sense of social responsibility, and committed to the permanent development of the region and the country.

Training a UCN engineer involves providing him/her with knowledge and tools he/she can apply so that he/she can be updated and able to show initiative to adapt to the professional demands associated with the environment. The UCN engineer is characterized by generic competences such as effective communication, permeability to change, leadership, and proactivity. In addition, he/she is an innovative professional, entrepreneuring, able to work in multidisciplinary teams, and solve problems arising among people or groups in all types of organization.

The UCN engineer can conceive, design, implement, and operate products, processes, and engineering systems, apart from planning, evaluating, and managing projects, considering the impact of these actions on the global, social, economic, and environmental context.

Learning outcomes

The UCN Civil Engineer Profile is based on the learning outcomes associated with knowledge, skills, and attitudes of the CDIO Syllabus, as stated below.

1. Scientific and Disciplinary Knowledge
    1.1 Apply knowledge in math and natural sciences, i.e., physics, chemistry, and biology to the solution of complex engineering problems.

1.2 Apply knowledge in engineering sciences to the solution of complex engineering problems.
1.3 Apply disciplinary knowledge, methods, and tools to the solution of complex engineering problems.

2. Personal and Professional Skills and Attitudes
   2.1 Identify, formulate, model, and solve complex engineering problems, considering variable interaction and dynamics.
   2.2 Apply the scientific method to design, lead, and conduct engineering research.
   2.3 Organize and integrate actual components, based on a systemic view and considering various perspectives.
   2.4 Show personal skills leading to successful engineering practice: initiative, decision-making, perseverance, critical thinking, continuous learning, creative thought, goal-orientation, flexibility, self-evaluation, and time and resource management.
   2.5 Act according to universal principles based on people's value and their whole development leading to personal realization, sense of justice, social responsibility, and equity.

3. Interpersonal Skills
   3.1 Lead and work in multidisciplinary teams.
   3.2 Communicate oral, written, and graphic technical information comprehensively in Spanish at an advanced level.
   3.3 Communicate verbal and written technical information comprehensively in English at an intermediate level.

4. Engineering Practice Skills
   4.1 Incorporate the global, social, health, safety, legal, cultural, and environmental context to the solution of engineering problems.
   4.2 Apply knowledge and skills acquired to contribute to the achievement of organizational goals.
   4.3 Conceive conceptual systems engineering for the efficient use of resources such as water, energy, raw materials, and residues.
   4.4 Design systems, components, and processes.
   4.5 Participate in the implementation of processes, equipment, and devices.
   4.6 Participate in the operation of plants, processes, equipment, and devices.
   4.7 Manage engineering projects and participate in innovation teams associated with systems, products, services, and processes.
   4.8 Participate in social, cultural, organizational, and entrepreneurial ventures.

Correlation between learning outcomes and other requirements.

Table 4 shows the correlations between the UCN civil engineer learning outcomes and

- CDIO Syllabus
- ABET criteria
- Latin America Tuning competences
- UCN Educational Project competences

TABLE 4

CORRELATION BETWEEN UCN CIVIL ENGINEER LEARNING OUTCOMES AND OTHER REQUIREMENTS

LEARNING OUTCOMES	CDIO Syllabus	ABET CRITERIA	TUNING COMPETENCES	UCN EDUCATIONAL PROJECT
Apply knowledge in math and natural sciences: physics, chemistry, and biology to the solution of complex engineering problems.	1.1	A	2-4	UCN-4
Apply knowledge in engineering sciences to the solution of complex engineering problems.	1.2	A	2-4	UCN-4
Apply disciplinary knowledge, methods, and tools to the solution of complex engineering problems	1.3	A-K	2-4-8	UCN-4
Identify, formulate, model, and solve complex engineering problems, considering variable interaction and dynamics.	2.1	E	1 – 11 – 15 - 13	UCN-4 UCN-5
Apply the scientific method to design, lead, and conduct engineering research.	2.2	B	9 – 11-14	UCN-5
Organize and integrate actual components, based on a systemic view and considering various perspectives.	2.3	C	1	
Show personal skills leading to successful engineering practice: initiative, decision-making, perseverance, critical thinking, continuous learning, creative thought, goal-orientation, flexibility, self-evaluation, and time and	2.4	I	3-10-12-13-14-16 – 18	UCN-3

resource management..				
Act according to universal principles based on people's value and their whole development leading to personal realization, sense of justice, social responsibility, and equity.	2.5	F	5 – 20- 21-22 -26	UCN-1
Lead and work in multidisciplinary teams.	3.1	D	17 – 18 -19	UCN-7
Communicate oral, written, and graphic technical information comprehensively in Spanish at an advanced level.	3.2	G	6 - 18	UCN-6
Communicate verbal and written technical information comprehensively in English at an intermediate level.	3.3	G	7 -18- 23	UCN-6
Incorporate the global, social, health, safety, legal, cultural, and environmental context to the solution of engineering problems..	4.1	C-F -H -J	5 – 10- 20 -21-22	UCN-2
Apply knowledge and skills acquired to contribute to the achievement of organizational goals.	4.2	K	2-27	UCN-9
Conceive conceptual systems engineering for the efficient use of resources such as water, energy, raw materials, and residues.	4.3	C	21-25-27	UCN-4
Design systems, components, and processes.	4.4	C	21-25-27	UCN-4
Participate in the implementation of processes, equipment, and devices.	4.5	C	21-25-27	UCN-4
Participate in the operation of plants, processes, equipment, and devices.	4.6	C	21-25-27	UCN-4
Manage engineering projects and participate in innovation teams associated with systems, products, services, and processes.	4.7	K	8-14 – 17-19-25	UCN-9
Participate in social, cultural, organizational, and entrepreneurial ventures.	4.8	K	8 – 24 -25	UCN-8 UCN-9

How can the profile of a specific program be defined?

The specific profile of civil engineering programs will include the following learning outcomes:

1.2. Apply knowledge in engineering sciences to the solution of complex engineering problems.
Observation: knowledge in engineering sciences relevant for a specific program must be defined.

1.3. Apply engineering knowledge, methods, and tools to the solution of complex engineering problems.
Observation: specific knowledge necessary for solving complex engineering problems must be determined.

4.3. Conceive conceptual systems engineering for the efficient use of resources such as water, energy, raw materials, and residues.
Observation: each specific program will define the systems to be conceived.

4.4. Design systems, components, and processes.
Observation: each specific program will define the systems, components, and processes to be designed.

4.5. Participate in the implementation of processes, equipment, and devices.
Observation: each specific program will define the processes, equipment, and devices to be implemented. The level of participation will be determined by the specific program, the highest being implementing. In addition, processes, equipment, and devices must be contextualized to the discipline.

4.6. Participate in the operation of plants, equipment, and devices.
Observation: each specific program will define the processes, equipment, and devices to be operated. The level of participation will be defined by the major, the highest being operating.

Once learning outcomes 4.3, 4.4, 4.5, and 4.6 are determined; each specific program must contextualize the general description of the UCN civil engineer (third par.) according to the specific discipline. This will lastly result in the graduation profile for each specific program.

CONCLUSIONS

The UCN engineer profile meets the CDIO Standard 2 (Learning Outcomes) at level 4 on the scale of criteria. Whose judgment is that the learning outcomes of the program are aligned with the institutional mission and vision and who have established proficiency levels for each outcome.

The UCN engineer profile is a good framework to build the profile of engineering programs because of that capture fluently and clear learning outcomes that graduates should possess.

The UCN engineer profile meets international and institutional standards and that links to the ABET criteria (criterion 3), Tuning skills and UCN Educational Project.

This methodology is suggested to perform the construction and renovation of engineering programs, given its consistency with the objectives of the program and its relevance to the practice of engineering.

REFERENCES

Edward Crawley “et al” (2007) Rethinking Engineering Education”. Springer Science Business Media. Library of Congress Control Number: 2007921087.

Edward F. Crawley (2001). The CDIO Syllabus. A statement of goals for undergraduate Engineering Education. http://www.cdio.org

ABET. Criteria for accrediting applied science programs. Copyright 2009 by ABET, Inc. http://www.abet.org.

Edward F. Crawley “et al” (2011). The CDIO Syllabus v2.0. An Updated Statement of Goals for Engineering Education. Proceedings of the 7th International CDIO Conference.

Reflexiones y perspectivas de la educación Superior en América Latina. Informe final Proyecto Tuning America Latina 2004-2007. . http://www.Tuningal.org.

Aurelio Villa, y Manuel Poblete (2007). Aprendizaje Basado en Competencias. Universidad de Deusto. Bilbao.

Proyecto Educativo. Universidad Católica del Norte. 2007. http://www.ucn.cl.

ANNEX

UCN Educational Project Competences

UCN-1. Respect for people's dignity.
UCN-2. Respect for cultural diversity and social responsibility.
UCN-3. Self-learning skills
UCN-4. Problem-solving skills
UCN-5. Information-learning skills
UCN-6. Communication skills in national and foreign contexts
UCN-7. Multidisciplinary and multicultural team work skills
UCN-8. Ability to start professional and vital projects
UCN-9. Ability to use new Information and Communications Technology (ICT).

ABET Criteria

A) An ability to apply knowledge of mathematics, science, and engineering
B) An ability to design and conduct experiments and well as to analyze and interpret data
C) An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health, and safety, manufacturability and sustainability
D) And ability to function on multidisciplinary team
E) An ability to identify, formulate, and solve engineering problems
F) An understanding of professional and ethical responsibility
G) An ability to communicate effectively
H) The broad education necessary to understand Thorough the impact of engineering solutions in a global, economic, environmental and societal context.
I) A recognition of the need for, and an ability to engage in life-long learning
J) A knowledge of contemporary about contemporary issues
K) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Tuning Competences

1. Abstraction, analytical, and synthesis skills.
2. Ability to apply knowledge to practical affairs.
3. Ability for time organization and planning.
4. Knowledge in the discipline and profession.
5. Social responsibility and citizenship commitment.
6. Oral and written communication skills.
7. Communication skills in a foreign language.
8. Ability to use ICT
9. Research skills.
10. Ability to learn and update knowledge.
11. Ability to search, process, and analyze information from different sources.
12. Critical and self-critical skills.

13. Ability to face new situations.
14. Creative skills.
15. Ability to identify, formulate, and solve problems.
16. Decision-making skills.
17. Team work skills.
18. Interpersonal skills.
19. Ability to motivate and lead to common goals.
20. Commitment to environmental preservation.
21. Commitment to the sociocultural environment.
22. Appreciation and respect for diversity and multiculturality.
23. Ability to work in international contexts.
24. Ability to work autonomously
25. Ability to formulate and manage projects.
26. Ethical commitment.
27. Commitment to quality.

BIOGRAPHICAL INFORMATION

María Hilda Flores, Chief of the Metallurgical Engineering Program at the UCN Department of Metallurgy and Mines. Academic Director of the Teaching Innovation Unit for Engineering Teaching Innovation at UCN. Has led the accreditation process of the technology-based Metallurgy Engineering Program and participated in the design of the Mining Engineering Program at the UCN Department of Metallurgy and Mines.

Alejandro Morales is academic in the Department of Metallurgical and Mining Engineering and Chief Career Civil Mining Engineering from Catholic University of the North, Antofagasta, Chile. Currently involved in the proposed re-design racing engineering from the Catholic University of the North.

Evelyn Melo A., is a Metallurgical Engineer now Professor Metallurgical and Mines Departament, Universidad Católica del Norte (UCN) and Ph D.Student in mineral process engineering. She collaborates regularly in redesign the engineering curriculum UCN.

Isabel Yel Carvajal, is an Industrial Engineer from the University of Antofagasta, Chile. Involved in the project performance 1204 "Reinventing Engineering", UCN, whose functions are Manage System Quality Management of Degree Engineering to ensure continuous improvement in the processes involved in the formation of professionals engineering.

Corresponding author

Ing. María Hilda Flores-Medel
Departamento de Metalurgia y Minas
Universidad Católica del Norte UCN
Avda. Angamos 0610
Antofagasta, Chile
+56-055-2355657
maflores@ucn.cl