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Transforming a Project-based Course: Learning Outcomes Assessment and Evaluation for Becoming a Professional Engineer

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Introduction

The human capacity for creativity and innovation in manipulating the natural environment, which gave rise to modern science [1], can be understood instrumentally as elements of technology —a means to an end that has enabled humanity to improve its quality of life. In this way, science becomes technology when applied to the invention and manufacture of material goods [2], which we now associate with the field of engineering. Characterized by using ingenuity to seek solutions, engineering has driven scientific innovations and technological advancements. Since becoming professionalized, it has consolidated itself as one of the most influential disciplines for solving practical problems [3]. This role brings responsibilities regarding resource use and the impact of its actions on the environment and people, underscoring the growing importance of quality certification in engineering programs and the granting of professional degrees.

One of the most influential countries in this field is the United States, which boasts some of the world's most prestigious engineering programs. According to the QS World University Rankings by Subject 2024: Engineering & Technology [4], the Massachusetts Institute of Technology (MIT) leads with the highest performance in individual subjects and is also ranked as the best university globally in engineering and technology overall. However, completing an engineering program, even at MIT, does not grant the right to practice as a Professional Engineer (PE). In the U.S., the responsibility for issuing professional licenses initially rested with individual states. By 1965, this system expanded to 30 states, with the first Fundamentals of Engineering (FE) exam. The following year, the National Principles and Practice of Engineering (PE) exam was introduced by the National Council of Examiners for Engineering and Surveying (NCEES) [5]. These exams now consist of multiple-choice questions developed by committees, graded by computers, and subjected to psychometric testing, granting engineering licenses in various disciplines [6]. Consequently, an individual has to meet the following requirements to become a PE: obtain a four-year engineering degree from an ABET-accredited program, pass the Fundamentals of Engineering (FE) exam, complete four years of progressive engineering experience under a PE's supervision, and pass the Principles and Practice of Engineering (PE) exam.

This process of attaining licensure is not necessarily equivalent to what occurs in other regions. In Latin America, licensure may only depend on demonstrating the achievement of a set of competencies upon completion of an engineering program. For example, in Chile, undergraduate engineering programs are subject to several regulatory specifications. Among these requirements, the engineering education curriculum must include a total duration of 3,200 to 3,600 instructional hours, of which at least 500 must be dedicated to professional internships. Although there is significant variability in completion of these programs nationwide [7], engineering training must culminate in a capstone project, a thesis, or passing a comprehensive examination, which may be part of credit requirements or plan-specific milestones.

According to guidelines established by the Chilean National Accreditation Commission (CNA) [8], engineering programs must ensure that their students acquire the necessary competencies to apply a distinctive set of scientific, mathematical, and technological knowledge dimensions. To promote timely professional certification, higher education institutions that offer engineering degrees must create exams and/or other type of assessment methods to properly assess students' mastery of the aforementioned dimensions. Therefore, in Chile, it is the engineering programs that deliver the professional certificate, and not an external entity as is the case in the United States.

To ensure that engineering programs are aligned with labor market needs and global competencies [9], several Chilean engineering faculties and schools have participated in a program titled 'New Engineering for 2030'. This initiative —funded initially by the Chilean Economic Development Agency (CORFO) [10] and later by the National Agency for Research and Development (ANID) — focuses on curriculum harmonization as one of its main goals. The objective of this study is to evaluate the transformation of a capstone course at Pontificia Universidad Católica de Chile in the context of its engineering 2030 project. This transformation implied changing assessment methods to measure the achievement of graduation profile competencies at both individual and group levels. By using a design-based research approach, this study aims to capture lessons learned that can be applied to engineering programs in South America, besides informing comparisons with similar practices in North and Central America. Considering that engineers are undertaking distributed work and collaborating in international endeavors, this work may inform further efforts to build a comprehensive framework to understand professional certification beyond borders.

Research context

The School of Engineering at Pontificia Universidad Católica de Chile offers professional certificates in civil engineering, industrial and systems engineering, among other specialties. By completing their program requirements, 825 students earned their professional licenses in 2023 and 733 in 2024. Until 2024, the main certification milestone was to take a final examination once completing all courses or conducting a work internship of 16 weeks. To improve timely graduation rates, these milestones were replaced by courses leading to the conferral of professional engineering licenses. These courses were called Certification Project Courses, and they will be implemented starting in 2025. Like capstone courses, these certification project courses aim to integrate prior knowledge acquired during the engineering program, ensuring the achievement of competencies outlined in the graduation profile and directly linked to professional qualifications. So far, there are 17 Certification Project Courses based on group projects, and this study focuses on one of them.

In this study, we explore the effort to design and implement this new certification milestone by examining the 'Project Evaluation' course, aimed at conferring the professional degree in Industrial and Systems Engineering. During this course, final-year students are expected to demonstrate their skills in evaluating real-world projects from companies, public institutions, and non-profit organizations. The course is designed to leverage all available information to apply financial methodologies and assess a project under strategic considerations, including the Net Present Value technique. Additionally, it seeks to strengthen professional skills, such as effective communication, teamwork, and ethical commitment in professional practice.

The course's methodological framework is primarily team-based. Students are organized into groups of approximately six members to carry out the project evaluation. The teaching staff comprises three types of instructors: the Guiding Professor, the Supervising Professor, and the Section Professor. Each team is assigned a Guiding Professor, typically an alumnus who is a former student of the course. Then, the Supervising Professor provides teams with additional support according to their expertise in the project's area (based on an honorary basis), while the Section Professor is a faculty member who oversees all teams within a section.

For the first semester of 2024, the course consisted of eight sections (about 36 students each), involving 45 projects/teams (240 students in total). In the second semester of 2024, the course had only two sections (also of about 36 students each), as it was defined as the first version of the certification project course, with a total enrolment of 56 students in total. This new version introduced simultaneous passing and graduation criteria, including an individual evaluation component with a failing threshold. A pilot of this evaluation was conducted during the first semester of 2024, which was essential for refining the course design and implementing the degree conferral version during the second semester of 2024.

Specifically, the graded activities of the course include both group-based and individual assessments. Group assessments involve delivering reports and oral presentations, while individual evaluations include the completion of an online course at the start of the semester titled “MOOC on Investment Project Evaluation”, and case development exercises and a reading comprehension test during the semester.

Methodology and results

This study addresses the following research question: *How can a course demonstrate the achievement of the competencies required for the professional practice of an engineer?* To answer this research question, we used factorial models to evaluate students’ ability to conduct financial and cost analyses applied to the requirements of private and public institutions; and to model solutions in complex and open systems of industrial engineering, adhering to technical, social, and ethical constraints. By following a design-based research approach, we aimed to support the improvement of the design of the ‘Project evaluation’ course, using learning outcome attainment for teaching staff reflection and course evaluation, allowing adjustments to optimize learning outcomes in future versions [11]. This research effort began in the first semester of 2024 with a pilot phase that informed improvement actions for the first official implementation in the second semester of 2024.

During the first semester of 2023, a case development assessment was used to directly measure students’ mastery of specific graduate competencies at an individual level. For this case-based assessment, the course coordinator established eight predefined items. The six items related to Costs, Sales Administration Expenses (SAE), Working Capital (WK), Taxes, Depreciation, and Net Present Value (NPV) were designed to be directly aligned to the competency of ‘Conducting financial and cost analyses applied to the requirements of private and public institutions.’ The two items about revenue and project recommendations were designed to be directly aligned the competency of ‘Modeling solutions for complex and open systems in industrial engineering that meet technical, social, and ethical constraints.’

Since competencies are complex constructs that cannot be directly observed, factorial models were used to analyze them as latent variables. However, initially, we lack evidence of the construct validity of the items—whether they actually measure the competencies they intend to assess. Therefore, following the recommendations of previous studies [12, 13], we opted for a two-step strategy: first, to develop hypotheses regarding the structure of emerging latent variables based on the data, and second, to evaluate whether the data provide evidence supporting (or not) this hypothetical structure.

To this end, data from the first and second semesters of 2024 were combined, and a random split was performed to create two subsamples. This aims to control possible circumstantial

relationships in a sample that could have influenced the results of the first analysis [13].
In one subsample, an Exploratory Factor Analysis (EFA) was conducted to identify dimensions emerging from the data [14]. Maximum Likelihood was used as the factor extraction method. Also, it seemed reasonable to expect that the two competencies being measured would be correlated, so oblimin rotation was chosen, which assumes correlations among latent factors.

In the other subsample, Confirmatory Factor Analysis (CFA) was performed to evaluate the goodness of fit of the factorial structure emerging from the exploratory analysis in the data [15]. The evaluation employed common indices: Standardized Root Mean Square Residual (SRMR), Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), and Tucker-Lewis Index (TLI). SRMR reflects the discrepancy between the covariance matrix of the original data and the one predicted by the model, while CFI measures whether the proposed model represents the data better than a null model, which is a model without a factorial structure. Thus, both are metrics of the overall model fit [15], [16]. RMSEA and TLI, on the other hand, inform about the model's parsimony, that is, the balance between fit and number of parameters, so values outside of the acceptance criteria suggest that the proposed model likely includes unnecessary parameters [15], [17]. The acceptance thresholds recommended in the literature [16], [17] were considered: SRMR < 0.08, CFI > 0.95, RMSEA < 0.05, and TLI > 0.90.

In the partition for the EFA (n=101), various methods were implemented to estimate the optimal number of factors to extract from the data. The indicators for complexity, empirical BIC, and root mean residual suggest that transitioning from two to three factors adds little additional information. In fact, the empirical BIC begins to increase again, which contradicts the expected trend of a continued decrease as more factors are added. Consequently, the optimal solution appears to be two factors.

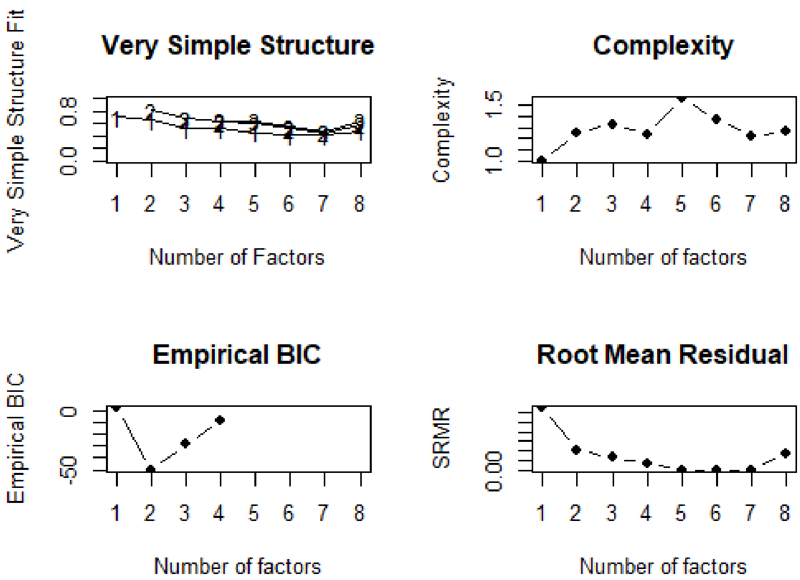

Figure 1. Indicators concerning the Exploratory Factor Analysis

The resulting two-factor model explains 50% of the original variance in the data (refer to Table 2). Cronbach's alpha was also calculated for each dimension, showing that only the first factor falls within the acceptable range (0.7), whereas the second factor yields a value that could be considered poor (0.66). This highlights issues with consistency in the latent dimensions being measured.

The factor loading matrix (Table 1) details the relationships between observed items and the latent factors identified by the model. The first factor (ML1) is associated with the items NPV (0.86), Revenue (0.71), Recommendation (0.69), Working Capital (0.69), and Costs (0.47). On the other hand, the Tax item shows a negative factor loading (-0.34). The second factor (ML2) is correlated with the items Depreciation (0.75), Tax (0.68), GAV (0.50), and Working Capital (0.31). It should be noted that these data-driven dimensions do not align with the theoretical model proposed by the course coordination team, which was mentioned at the beginning of this section, that is, the six items related to Costs, Sales Administration Expenses (SAE), Working Capital (WK), Taxes, Depreciation, and Net Present Value (NPV) directly aligned to the competency of 'Conducting financial and cost analyses applied to the requirements of private and public institutions.', while the two items about revenue and project recommendations are aligned the competency of 'Modeling solutions for complex and open systems in industrial engineering that meet technical, social, and ethical constraints.'

Table 1. Factor loadings matrix

Item	ML1	ML2	Communality	Complexity
VAN	0.86		0.71	1.06
Revenue	0.71		0.57	1.08
Recommendation	0.69		0.54	1.08
WK	0.49	0.31	0.41	1.69
Costs	0.47		0.27	1.18
Depreciation		0.75	0.70	1.22
Tax	-0.34	0.68	0.47	1.48
GAV		0.50	0.33	1.25

Table 2. Fit indices

	ML1	ML2
SS loadings	2.48	1.52
Proportion Var.	0.31	0.19
Cumulative Var.	0.31	0.50
Proportion Explained	0.62	0.38
Cumulative Proportion	0.62	1.00
Cronbach's Alpha	0.70	0.66

This data-driven factorial structure was tested using CFA on the evaluation data partition (n=102). Although all proposed relationships between observed items and latent variables are statistically significant, the model fit metrics tend to fall outside the thresholds considered acceptable (CFI = 0.8873, RMSEA = 0.1952, TLI = 0.8340). Only the SRMR is within the acceptable range (0.0718), which indicates that while the model is relatively capable of reproducing the covariance matrix of the data, it does not represent the data better than a null model. Furthermore, the model does not appear to exhibit parsimony, suggesting that unnecessary parameters are included.

Table 3. Confirmatory Factor Analysis results

Latent variable	Observed variable	Estimate	*SE*	*Z*	*p*-value
ML1	VAN	0.77	0.00		
ML1	Revenue	0.78	0.19	8.40	0.00
ML1	Recommendation	0.40	0.16	4.03	0.00
ML1	WK	0.92	0.24	10.34	0.00
ML1	Costs	0.87	0.23	9.60	0.00
ML2	Depr	0.94	0.00		
ML2	Tax	0.70	0.05	8.98	0.00
ML2	GAV	0.85	0.06	13.26	0.00

Table 4. Fit indices of theoretical model

RMSEA	SRMR	CFI	TLI
0.1984	0.0737	0.8837	0.8285

Discussion and limitations

This study provides researchers and practitioners with empirical evidence to understand that the assessment of the competencies required for the professional practice of an engineer is far from trivial. Performance-based evaluations within a course present significant challenges compared to external examinations, as they require aligning specific items with the competencies being measured. Considering the results from both semesters in the ‘Project Evaluation’ course, there is a clear need to adjust the case study evaluation used to measure competency attainment at an individual level. The measurements are inconsistent and do not effectively identify the competencies defined at an instructional level. Therefore, the achievement of competencies cannot be determined based on the factor loading analysis.

Despite the collaboration between the Engineering Education Unit and the teaching team of the Project Evaluation course during the first and second semesters of 2024, the formulation of improvement actions between semesters was insufficient to enhance the assessment of professional competencies. The modifications discussed among all stakeholders to improve the case study evaluation did not capture the achievement of competencies, as the emerging dimensions from the data did not align with the theoretical model proposed by the course coordination team.

In this context, the importance of institutional responsibility is evident. The institution must foster greater rigor in the development of assessment and evaluation methods for conferring professional licenses for engineers. However, this often does not align with the standards of external bodies, governed by the Washington Accord, whose review process for the quality of engineering education—certified even at an international level—has less stringent criteria. This asymmetry can be an opportunity for continuous institutional improvement, understanding that if institutional standards are more rigid, it will ensure that external certification always has high-quality, contextually relevant input for evaluation, based on what the institution has defined as relevant criteria. Additionally, the process of conferring professional licenses varies significantly between countries, highlighting the need for a global perspective in improving these processes, considering the international collaboration among engineers.

Finally, as lessons learned, and understanding that this curriculum is competency-based, where professional competencies define the effective exercise of capabilities necessary for job performance—such as behaviors, analytical skills, decision-making, and information transmission—a more significant intervention in this course is anticipated. The competencies measured will become part of a continuous improvement process to systematically evaluate the design and implementation go these new courses. Undertaking factorial analysis to evaluate competencies as latent variables of assessment items may be crucial, as it may inform program committees as they discuss course results and formulate continuous improvements. Nevertheless, these efforts should also be understood within the context of this being the first course for professional licensing in the research site, which naturally brings with it lessons and mistakes in its initial versions.

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