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Article

Analysis of generic and specific competencies of Industry 4.0 in Engineering students from the Laguna region

Análisis de las competencias genéricas y específicas de la Industria 4.0 en estudiantes de Ingeniería de la región Lagunera

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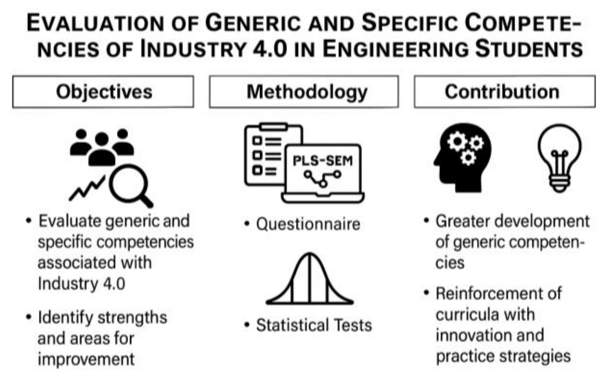
Abstract

The challenges faced by university graduates when entering the labor market require concrete, short-term actions. This study examined the generic and specific competencies associated with Industry 4.0, promoted by the World Economic Forum, for university students in the Laguna region. A total of 262 engineering students were surveyed, and a PLS-SEM model was estimated with evaluation of reliability, validity, and predictive relevance. The participating engineering programs are: Computer Systems, Environmental Technology, Logistics, Electrical Systems, Business Management, Agrobiotechnology, Industrial Engineering, Advanced Manufacturing, Agronomy, Food Science, and Administration. The results indicate positive effects of generic and specific competencies on engineering students at universities in the Laguna region. The model explains 72.1% of the variance in the dependent variable: Industry 4.0. The research hypotheses are accepted with a highly significant result. And a Q2 of 0.403, registering a moderate to high predictive power.



Generic Competencies, Specific Competencies, Industry 4.0

Resumen

Los retos que enfrenta los egresados universitarios al integrarse a un mercado laboral, exigen acciones concretas en un corto plazo. Este estudio examinó las competencias genéricas y específicas asociadas a la industria 4.0 y promovidas por el Fondo Económico Mundial a estudiantes universitarios de la región lagunera. Se encuestó a 262 estudiantes de ingeniería y se estimó un modelo PLS-SEM con evaluación de fiabilidad, validez y relevancia predictiva. Las ingenierías participantes son: Sistemas Computacionales, Tecnología Ambiental, Logística, Sistemas Eléctricos, Gestión Empresarial, Agrobiotecnología, Industrial, Manufactura Avanzada, Agronomía, Alimentos y Administración. Los resultados indican efectos positivos de las competencias genéricas y específicas en alumnos de ingeniería de universidades de la región lagunera. El modelo explica en un 72.1% la varianza de la variable dependiente: Industria _4.0. Se aceptan las hipótesis de investigación con un resultado altamente significativo. Y un Q^2 de 0.403, registrando un poder predictivo de moderado a alto.

Competencias Genericas, Competencias Especificas, Industria 4.0

Area: Strengthening the scientific community

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Introduction

The emergence of the Fourth Industrial Revolution, also known as Industry 4.0, has profoundly transformed production systems by integrating emerging technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data, additive manufacturing, augmented reality, and cyber-physical systems. These advances have generated new demands in the labor market, requiring professionals not only to possess technical knowledge but also to develop transversal competencies that enable them to adapt to highly dynamic, digitalized, and competitive environments.

Industry 4.0 has brought about a significant shift in production systems, characterized by the digitalization and interconnectivity of industrial processes. This revolution incorporates technologies such as the Internet of Things (IoT), artificial intelligence, big data, additive manufacturing, robotics, augmented reality, and cyber-physical systems, among others, which have radically transformed the skill set required in professional contexts—particularly in the field of industrial engineering. Industry 4.0 represents a profound transformation in production systems by integrating emerging technologies such as the Internet of Things, artificial intelligence, big data, and simulation.

In this context, it is crucial for industrial engineers to develop both generic and specific competencies that allow them to adapt to new smart-manufacturing environments. Studying this topic is essential, as it ensures that future professionals acquire the necessary skills to face the technological and organizational challenges of the Fourth Industrial Revolution, thereby contributing to the competitiveness of enterprises and the nation as a whole.

In this context, universities and higher education institutions face the challenge of updating their academic programs to prepare graduates capable of meeting the demands of an increasingly automated, digital, and competitive industrial environment. In this regard, numerous studies and initiatives have emerged aiming to define the generic and specific competencies that future engineers must possess.

According to the World Economic Forum (2018), the key competencies required to thrive in the context of Industry 4.0 include complex problem-solving, critical thinking, creativity, emotional intelligence, decision-making, the ability to work in interdisciplinary environments, and adaptability. These skills are part of what is known as generic competencies, applicable to a wide range of professional contexts. On the other hand, studies such as those by Prifti et al. (2017), Terrés et al. (2017), and Karre et al. (2017) have identified specific competencies related to the mastery of technological tools, such as the use of simulation software, programming, data analysis, and computer-aided design.

Regarding digital transformation, which has become a key component of Industry 4.0, the education of future professionals requires the strengthening of both generic and specific competencies. The latter are essential for mastering tools, methodologies, and technical knowledge that enable individuals to effectively address the challenges of the current productive environment.

In this context, higher education institutions face the challenge of preparing graduates capable of responding to these demands by strengthening both generic competencies—such as critical thinking, creativity, emotional intelligence, and complex problem-solving—and specific competencies related to the mastery and application of technological tools inherent to Industry 4.0.

The purpose of this study is to examine the generic and specific competencies of university students who are about to graduate from four universities in the Laguna region. Surveys were administered across institutions in the Laguna region, providing a broad perspective on the current state of academic training in relation to the needs of the labor market.

This research aims to provide guidelines that contribute to the improvement of educational programs, promoting a comprehensive training approach that ensures the successful integration of future professionals into smart manufacturing environments.

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However, the results obtained from the survey administered to senior university students across three different institutions reveal a concerning situation. When assessing the development of specific competencies, most respondents selected the option “sometimes” for all questions within this category. This response, positioned at an intermediate point on the proposed scale (“always,” “almost always,” “sometimes,” “almost never,” “never”), reflects a perceived insufficiency or inconsistency in the acquisition of these competencies during their academic training.

This finding suggests that although students may have had some exposure to the content or skills associated with specific competencies, they do not feel fully prepared to apply them consistently or effectively in a professional setting. This situation represents both a concern and a limitation in terms of competing for employment positions given the demands of Industry 4.0, which requires mastery of areas such as artificial intelligence, the Internet of Things, virtual reality, additive manufacturing, blockchain, big data, simulation, horizontal and vertical system integration, cybersecurity, cloud computing, cyber-physical systems, and machine-to-machine (M2M) communication.

The lack of acquisition of these competencies could directly affect graduates’ ability to successfully enter the labor market and to respond proactively to the technological and organizational challenges of the current industrial sector. Therefore, this issue highlights the need to review and strengthen curricular content, teaching strategies, and learning environments in higher technological education, in order to ensure training that meets the demands of the Fourth Industrial Revolution.

It is essential to adapt educational programs for future professionals to the current needs of the labor market, enabling the development of graduates capable of effectively responding to the requirements of an automated, connected, and flexible industry. Likewise, this knowledge will allow higher education institutions to implement pedagogical and curricular strategies aligned with the competencies demanded by Industry 4.0, such as data analysis, the integration of cyber-physical systems, and the ability to make decisions in complex environments.

The hypotheses proposed are as follows: H1: University students’ generic competencies have a positive and significant influence on Industry 4.0; H2: University students’ specific competencies have a positive and significant influence on Industry 4.0.

Methodology

The present study adopts a quantitative approach with a non-experimental, cross-sectional design and an explanatory scope with causal correlation. For data analysis, the software programs SMART PLS v3.02 (Ringle et al., 2015) and IBM SPSS Statistics 29 were employed. The measurement instrument consisted of 23 items and was administered to 262 university students. Based on an extensive literature review, the study focuses on validating the existence of an effect of the independent variables—employment status and employment relationship—on the dependent variable, work commitment.

Data collection was conducted through a Google Forms questionnaire, using a five-point Likert-type scale (from 1 to 5, with 5 being the highest value). Composite reliability was assessed, which is a more advanced measure that considers the individual factor loadings of each item and their associated errors.

This approach provides greater precision than Cronbach’s alpha, particularly in more sophisticated analyses such as confirmatory factor analysis (CFA) or structural equation modeling (SEM). Since greater accuracy is required and the analysis is based on a factorial model, composite reliability is considered a more appropriate reliability indicator. In addition, various analyses were performed to validate the assumptions of the model in multiple linear regression, including tests of homoscedasticity, linearity, normality, model fit, and data adequacy.

The study sample consisted of 262 students, and the internal reliability of the variables was evaluated using Cronbach’s alpha coefficient. Additionally, composite reliability was employed to validate internal consistency. The structural model was analyzed through structural equation modeling using PLS-SEM, with standardized coefficients employed to test the proposed hypotheses.

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The normality analysis (Kolmogorov–Smirnov test), as well as discriminant validity—confirmed through the Fornell–Larcker criterion—and collinearity tests ruled out multicollinearity issues. Finally, the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's test of sphericity, along with factor analysis, were conducted to validate the contribution of the items to the variance of the factors.

Results

Figure 1 presents the proposed structural model designed to analyze the relationship between generic competencies (X1), specific competencies (X2), and their influence on the dependent variable Industry 4.0 (Y). The model was estimated using the Partial Least Squares Structural Equation Modeling (PLS-SEM) method, with the objective of evaluating the contribution of these competencies to professional development oriented toward digital transformation.

Box 1

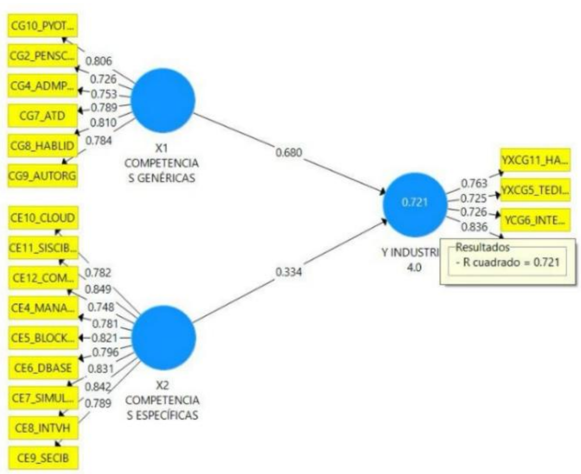

Figure 1
SmartPLS output

Source: Own Elaboration

Using Pearson's coefficient of determination (R^2), 72.1% of the variability in students' competency levels is explained by the two evaluated dimensions: generic competencies (X1) and specific competencies (Y1). Likewise, regarding the adjusted R^2 value (71.9%), and following Hair et al. (2021), this value is considered acceptable in social science research, as it demonstrates a significant relationship among the variables. Figure 2

Box 2

R cuadrado

Matriz | R cuadrado | R cuadrado ajustada

	R cuadrado	R cuadrado ajustada
Y INDUSTRIA 4.0	0.721	0.719

Figure 2
R^2 and Adjusted R^2 Values

Source: Own elaboration

Regarding the Durbin–Watson statistic (Figure 3.), a value of 1.955 was obtained, which falls within the acceptable threshold of 1.5 to 2.5, confirming the independence of residuals.

Box 3

Resumen del modelo[b]

Error estándar de la estimación	Estadísticos de cambio					Durbin-Watson
	Cambio en R cuadrado	Cambio en F	gl1	gl2	Sig. Cambio en F	
,68585	,019	2,314	2	240	,101	1,955

ESPECÍFICAS, X1_COMPETENCIAS_GENERICAS

Figure 3
Model Summary

Source: Own Elaboration

The Fisher's F value (71.478) is statistically significant, validating the presence of meaningful variations within the analyzed sample Figure 4.

Box 4

ANOVA[a]

Modelo		Suma de cuadrados	gl	Media cuadrática	F	Sig.
1	Regresión	31,178	2	15,589	71,478	<,001[b]
	Residuo	52,343	240	,218		
	Total	83,522	242			

a. Variable dependiente: Y COMPETENCIAS DE INDUSTRIA RL 4.0
b. Predictores: (Constante), X2_COMPETENCIAS_ESPECÍFICAS, X1_COMPETENCIAS_GENERICAS

Figure 4
ANOVA

Source: Own Elaboration

Figure 4. Regarding the analysis of variance (ANOVA), the results show a highly significant level of 0.001, indicating that at least one of the analyzed variables contributes significantly to the explanation of the model. The population sample consisted of *n* = 243 students, confirming the validity of the mean comparison among groups, since in the statistical treatment, 19 remaining data points were identified as outliers.

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The standardized coefficients obtained in the model indicate that the variable X1, *generic competencies* (β = 0.680; t = 18.930, p = 0.000), exhibits a strong and statistically significant effect, leading to the acceptance of the corresponding research hypothesis. This suggests that skills such as critical thinking, problem-solving, emotional intelligence, and creativity are well developed among soon-to-graduate students. In contrast, the variable X2, *specific competencies* (β = 0.334; t = 7.554, p = 0.000), shows a moderate-to-strong effect with a t-value above the critical threshold of 1.96 and highly significant values ($p < 0.05$), indicating that mastery of areas related to big data, artificial intelligence, IoT, and cyber-physical systems still requires further strengthening. Figure 5.

Box 5

	Muestra original ...	Media...	Desviación est...	Estadísticos t ...	P Valores
X1 COMPETENCIAS GENÉRICAS -> Y INDUSTRIA 4.0	0.680	0.680	0.036	18.930	0.000
X2 COMPETENCIAS ESPECÍFICAS -> Y INDUSTRIA 4.0	0.334	0.336	0.044	7.554	0.000

Figure 5
Standardized Coefficients of the Model
Source: Own Elaboration

The Variance Inflation Factor (VIF) presented a value of 1.117, which, being below the threshold of 5.000, confirms the absence of multicollinearity among the model variables Figure 6.

Box 6

Estadísticos de colinealidad (VIF)

Valores VIF del modelo externo ... | Valores VIF del modelo estructur... | Copiar en e

	X1 COMPET...	X2 COMPET...	Y INDUSTRIA 4.0
X1 COMPETENCIAS GENÉRICAS			1.117
X2 COMPETENCIAS ESPECÍFICAS			1.117
Y INDUSTRIA 4.0			

Figure 6
The Variance Inflation Factor (VIF)
Source: Own Elaboration

The histogram of standardized residuals (Figure 7) shows a normal distribution of the data, fitting the Gaussian curve and confirming a mesokurtic behavior of the model. Complementarily, the Kolmogorov–Smirnov test validates the normality of the sample (n = 243), confirming that the data are significantly distributed under a two-tailed asymptotic behavior

Box 7

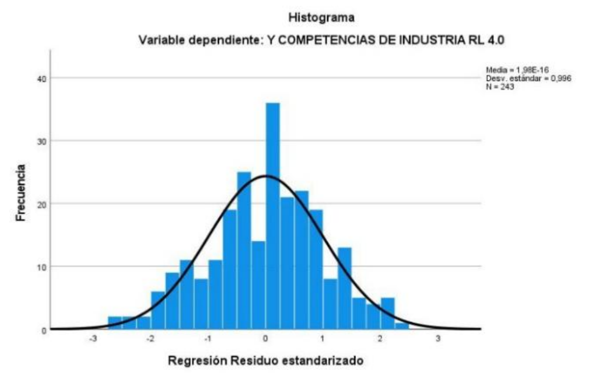

Figure 7
The histogram of standardized residuals
Source: Own Elaboration

The P–P regression plot of standardized residuals (Figure 8) demonstrates compliance with the linearity criterion, showing that the observations are distributed closely along the line of estimation, which represents an adequate model fit between generic and specific competencies.

Box 8

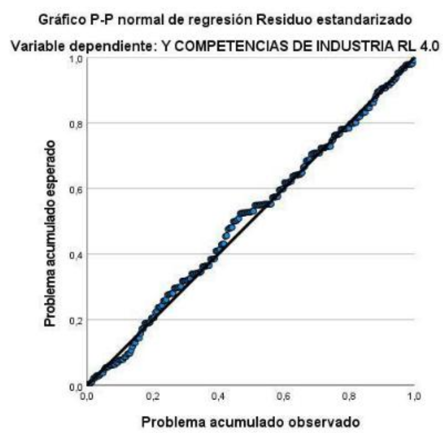

Figure 8
The P–P regression plot of standardized
Source: Own Elaboration

Finally, the results of the internal consistency reliability analysis (Figure 9) show that the instrument used was both consistent and valid: for X1 (*generic competencies*), Cronbach's alpha was 0.870; for X2 (*specific competencies*), the value was 0.932; and for the dependent variable E (*Industry 4.0*), the value was 0.763. All values exceeded the acceptable threshold of 0.70. This confirms that the items used to measure these variables are reliable and appropriate for assessing students' preparedness to face the challenges of Industry 4.0.

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Box 9

	Alfa de Cronbach	rho_A	Fiabilidad compuesta	Varianza extraída media (AVE)
X1 COMPETENCIAS GENÉRICAS	0.870	0.871	0.902	0.606
X2 COMPETENCIAS ESPECÍFICAS	0.932	0.936	0.943	0.648
Y INDUSTRIA 4.0	0.763	0.783	0.848	0.584

Figure 9
Cronbach's alpha

Source: Own Elaboration

Therefore, regarding the analysis of predictive power using the Stone–Geisser Q^2 test (Figure 10), the model demonstrates predictive relevance for the specific constructs, yielding a value of 0.407. This result indicates a moderate predictive relevance ($Q^2 \geq 0.35$) within the analytical context, suggesting that the model predicts reasonably well, although not with excellent precision.

Box

Redudancia de constructo validada de forma cruzada

Total | Caso1 | Caso2 | Caso3 | Caso4 | Caso5 | Caso6 | Caso7

	SSO	SSE	Q² (=1-SSE/S...
X1 COMPETENCIAS GENÉRICAS	1476.000	1476.000	
X2 COMPETENCIAS ESPECÍFICAS	2214.000	2214.000	
Y INDUSTRIA 4.0	984.000	583.274	0.407

Figure 10
Stone–Geisser Q^2 test

Source: Own Elaboration

Conclusions

The diagnostic analysis reveals that students nearing graduation demonstrate an acceptable level of development in generic competencies, whereas specific competencies still represent a significant area for improvement. Among the most relevant findings, it was identified that 66.6% of respondents consider themselves prepared for problem-solving, reflecting a positive mastery of this generic competency. Meanwhile, 43.1% indicated that they almost always engage in analysis and decision-making, while 41.1% reported that they almost always develop planning and work organization skills.
With respect to emotional intelligence, most students perceive that it is consistently fostered, which strengthens their ability to adapt to interdisciplinary environments.

On the other hand, the results for specific competencies were less favorable: 44.9% of respondents indicated that they only "sometimes" develop skills related to artificial intelligence and robotics.

Similarly, 46.1% reported that they "sometimes" work with big data and data analysis, revealing limited preparation in this area. Between 39% and 41% of the participants stated that they only "sometimes" apply skills in virtual reality, cyber-physical systems, cloud computing, and M2M communication, which demonstrates that their learning has been partial and lacks consistent practice. These results lead to the conclusion that, although students show strengths in generic competencies such as critical thinking, creativity, and problem-solving, they exhibit notable weaknesses in specific competencies directly linked to Industry 4.0. This situation represents a risk for their insertion into the labor market, as it limits their ability to interact effectively with the emerging technologies that characterize smart manufacturing environments.

Therefore, the findings confirm the need for higher education institutions to strengthen their curricula through strategies that enhance practice, innovation, and the real-world application of these technologies. The goal is to achieve a balance between generic and specific competencies and to ensure that future professionals are able to respond competitively to the challenges of the Fourth Industrial Revolution.

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