Online-Journals.org

iJEP International Journal of Engineering Pedagogy

iJEP | eISSN: 2192-4880 | Vol. 13 No. 3 (2023) | OPEN ACCESS

https://doi.org/10.3991/ijep.v13i3.36885

PAPER

Complex Thinking and Its Relevance in Professional Training: An Approach to Engineering Students in a Mexican University

Marco Cruz-Sandoval[1](✉), José Carlos Vázquez-Parra[2], Martina Carlos-Arroyo[2], Marco Vinicio del Angel-González[3]

[1]Center for the Future of Cities, Tecnologico de Monterrey, Monterrey, Mexico

[2]Institute for the Future of Education, Tecnologico de Monterrey, Monterrey, Mexico

[3]Center of Linkage and Professional Development, Tecnologico de Monterrey, Monterrey, Mexico

cruzsandovalmarco@tec.mx

ABSTRACT

This article aims to present the results of an analysis of the level of perceived achievement of the complex thinking competency among a group of engineering students in their last semester at a university in Western Mexico. The intention is to identify whether this population has the necessary skills to meet challenges and solve problems related to the demands of their future professional environments. Specifically, we not only seek to know the level of perception of achievement of complex thinking but also to understand its behavior and the possible existence of differences between the male and female populations. Methodologically, exploratory and multivariate descriptive statistical analyses were carried out. The results showed that the participants felt a high level of perceived achievement of the complex thinking competency, which was more noticeable in the male population.

KEYWORDS

professional education, educational innovation, future of education, complex thinking, engineering training, higher education

1 INTRODUCTION

Contemporary professionals face challenges that often go beyond the theoretical knowledge they acquired in their training process, requiring skills and competencies that integrate their discipline, environment, and the challenges of fluid and constantly changing reality. Globalization, the promotion of diversity, inclusion, multiculturalism, and other phenomena are elements of complex contexts requiring similar competencies [1].

Complex thinking is the capacity of an individual for integrated reasoning that allows the managing of information to resolve problems in their environment,

Cruz-Sandoval, M., Vázquez-Parra, J.C., Carlos-Arroyo, M., del Angel-González, M.V. (2023). Complex Thinking and Its Relevance in Professional Training: An Approach to Engineering Students in a Mexican University. *International Journal of Engineering Pedagogy (iJEP)*, 13(3), pp. 100–119. https://doi.org/10.3991/ijep.v13i3.36885

Article submitted 2022-11-16. Resubmitted 2023-01-28. Final acceptance 2023-01-28. Final version published as submitted by the authors.

© 2023 by the authors of this article. Published under CC-BY.

considering knowledge, skills, and attitudes necessary for the analysis and synthesis of data and the development of a continuous learning process [2]. Universities have paid attention for years to the formative processes of complex thinking as a competency for life, valuing that acquiring and developing this competency can provide an advantage for their graduates in their futures as professionals [3].

Faced with a reality in constant flux and the uncertainty of changes, future professionals must acquire and develop complex thinking as a fundamental competency, providing the necessary cognitive tools to face challenges and propose viable, sustainable, and comprehensive solutions [4]. However, from its integration, the competency of complex thinking comprises several types of thinking and styles of argumentation that are more related to specific disciplines and the challenges they face. It is necessary to associate how this competency and its subcompetencies can be configured for the students' professional profiles [5]

Based on the above, this article aims to present the results of a study on a group of engineering students in their last semester at a university in Western Mexico. The motivation for this quasi-experimental intervention was to identify their level of perception of achievement of complex thinking to provide information to design a professional profile related to this competency and its sub-competencies to improve the pedagogical model in this disciplinary area. The theoretical framework provides an overview of engineering education in Latin America, and specifically in Mexico, focusing on the importance of considering transversal competencies and skills as part of the teaching process. Thus, we seek to expose the relevance of complex thinking as a valuable competency for the professional profile of engineering students. Methodologically, we performed an exploratory and a multivariate descriptive statistical analysis.

1.1 Theoretical framework

Professional training in the area of engineering. Engineering has a transcendental role in the development of society. Every engineering professional applies, builds, and recreates science and technology to improve infrastructure, processes, and material resources that increase productivity, wealth, and the population's quality of life. Engineering has dehumanized the theories and the processes underlying consumer objects that today we consider indispensable; for example, cellular telephones, the internet, medical devices, technology, and space, among others [6].

On the other hand, the dynamics of everyday life, the challenges, and current problems entail a constant evolution of views and training processes. In this sense, training for engineering throughout history, since the ancient world, as an exercise "competed with natural forces and dominated them, as a profession attentive to the invention of war devices, water extraction machines, roads, canals, bridges, draining of swamps, subway galleries, large port facilities, city defenses" [7]. In Latin America, according to Vargas [8], engineering has gone through three periods (Figure 1).

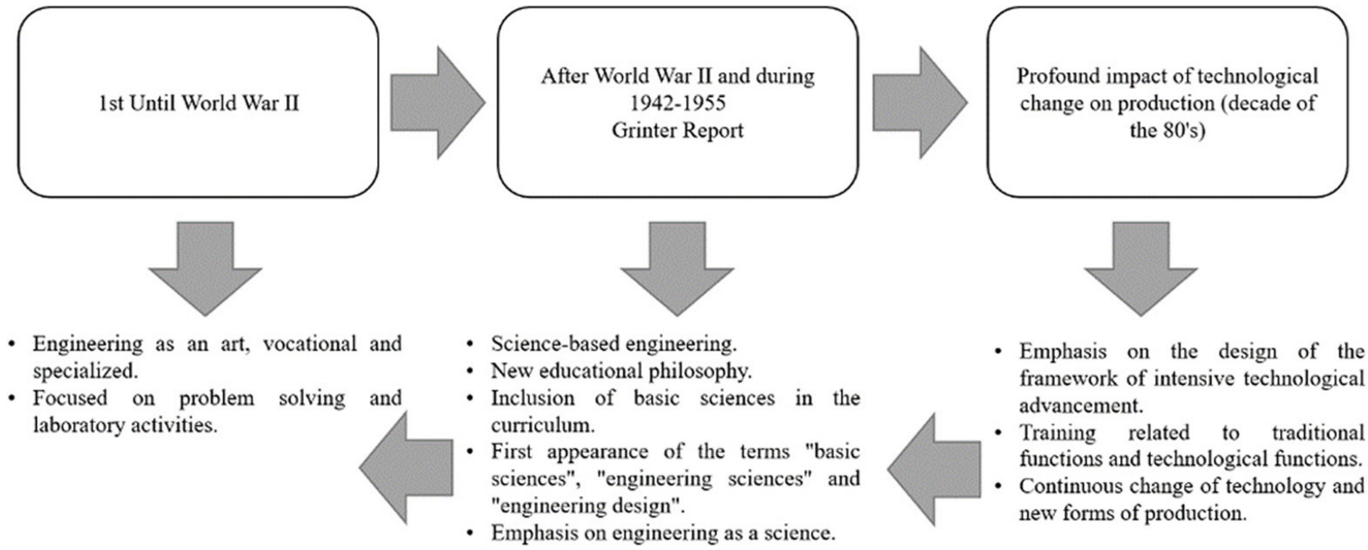

Fig. 1. Periods of engineering in Latin America. created by the authors based on Vargas [8]

According to Dettmer [9], Mexican engineering was recognized at the beginning of the twentieth century, brought to the country through technological transfer by foreign engineers and technicians who contributed to the design, construction, and development of agricultural, industrial, and service infrastructures. This transfer by foreign engineers and technicians was abandoned at the end of the 40s due to higher education institutions' training programs. In the 80s, Mexican engineering education and training became self-sufficient in civil, seismic, and hydraulic engineering, while electrical and electronic engineering still required imports.

Vega [10] comments that, nowadays, engineering training requires the inclusion of training aspects that generate human, business, and managerial competencies in addition to the specific theoretical and scientific training in the area. He proposes training in oral and written communication, teamwork, interpersonal management skills, emotional intelligence, ethics, and moral autonomy for human competencies. He suggests acquiring business and management competencies by including learning for life, creativity, leadership, administration, new-product development, and entrepreneurship.

Similarly, regarding the trends in engineering education, Álvarez and García [11] stated the need and importance of including in engineering education topics that address strategic problems at a planetary level, among them:

- Energy
- Food
- Health
- Environment
- Mobility
- Complexity as a perspective to understand problems and phenomena beyond mathematics and science

To this end, they considered that "the engineer is a social being of global action … with generic and systemic capabilities within flexible environments" (pages 6 and 7). Therefore, the training must prepare new engineers to offer solutions at the technical and economic levels for concrete and local answers to social problems so that as part of the professional profile, the socioeconomic and humanistic competencies will favor the management, design, planning, and development of projects with a global impact [12].

Although it can be seen that there is a common basis for engineering education, each institution, based on its mission, sets its parameters for the profile of its professionals, considering traditional visions of the teaching of basic sciences or a greater openness to considering complementary skills and competencies that provide a more diverse, flexible, and updated profile [13].

The competency of complex thinking for training in engineering. Complex thinking or reasoning refers to the ability of people to apply integrative thinking that enables them to analyze and synthesize information for problem-solving and developing continuous learning [14]. When reference is made to complex thinking, it includes quantitative, qualitative, algorithmic, analogical, contextual, combinatorial, fuzzy, imaginative, provisional, heuristic, and ethical reasoning [15].

At the professional level, the competency of complex thinking allows individuals to face the challenges of reality integrally and strategically, considering diverse disciplines and approaches within their analysis and choices [16]. Therefore, complex thinking determines how people perceive their ability to solve their problems and the intellectual tools they need to face difficulties [17]. Within the complexity of this competency, the mastery of four types of thinking or sub-competencies is valued: systemic, scientific, critical, and innovative.

- *Systemic Thinking* is the ability to analyze problems integratively, considering inter- and transdisciplinarity. Systemic thinking allows the appreciation of reality in an interconnected way, considering its complexity and recognizing its multiple elements [18].
- *Scientific Thinking* is based on problem-solving from a vision and objective, validated, and standardized methods that address reality considering structures of inquiry and evidence-based research. Such research gives certainty to decision-making processes in the complex world [19].
- *Critical Thinking* is a sub-competency that allows individuals to evaluate the validity of reasoning to make logical judgments in a situation or problem [20]. In addition, it enables the individual to analyze and evaluate the current information on a topic or problem, discerning what reality does not say and thus being able to reach a level of understanding that enables making a decision [21].
- *Innovative (or creative) Thinking* refers to creativity and processes focused on solving complex problems; in addition, it has an interdisciplinary character that drives the organization of processes and knowledge using new approaches [22]. The role of creativity is easily recognized in professional artistic and entrepreneurial areas, along with other competencies such as teamwork and achievement skills [23]–[25]. However, innovative thinking or creativity has a place in all Industry 4.0 disciplines, including the humanities, engineering, and sciences.

Although Morin proposes the need to develop complex thinking integratively, i.e., including all its sub-competencies, some studies suggest a more significant development of sub-competencies in individuals from specific disciplines, considering the challenges and problems they face, forcing them to make particular skills more efficient than others. For Azurín [26], Eyzaguirre [27], and Gutiérrez and Medina [28], critical thinking is characteristic of the humanities, social sciences, and architecture; their professionals need to analyze, reflect, and question their reality to interact and transform it. On the other hand, for Cardozo [29], León, Barrios, del Carmen, Arévalo, Rincón, and Pérez [30] and Mendoza [31], systemic thinking is fundamental for the area of business and the constitution of companies, considering that this type of reasoning turns out to be very important for the development of corporate social responsibility, the creation of intelligent organizations, and administrative management in general. Finally, we can consider the contributions of Paredes [32], Ruidiaz Villalobos [33], Colina and Camacho [34], and Rojas and Cortés [35]. They see in the medical and engineering areas the most significant development of scientific thinking because they are disciplines in which the use of the scientific method, objective evidence, measurable data, and replicable results are encouraged. Although the scientific method can be used in any disciplinary area, it is in the STEM disciplines where more work has been done on its adoption, implementation, and development.

Even so, despite these studies that categorize argumentation according to its area of training, an increasing tendency on the part of educational institutions is to avoid this reductionist view, considering that mainly encouraging one type of thinking can be limiting for students when they enter the contemporary world. For Vázquez and Manassero [36] and Chamizo [37], STEM areas should not be limited to the exclusive development of scientific thinking, just as the use of the scientific method should not be excluded from the training in other disciplines; both improve implementation and problem-solving processes by considering systemic and critical argumentation. Other disciplines could better structure their processes for collecting, analyzing, and synthesizing information by adopting validated methodologies. Thus, according to Vázquez-Parra, Castillo-Martínez, Ramírez-Montoya, and Millán [38], the development of complex thinking competency integratively is necessary for all professionals, and the types of thinking that have been stereotypically limited to specific disciplines should be encouraged as a priority for all.

In this line of analysis, the present article seeks to measure the perception of achievement of the complex thinking competency both in general and in each of its subcompetencies, considering them relevant skills for any profession, including those associated with engineering education.

2 METHODOLOGY

2.1 Participants and procedure

A convenience sample of 146 engineering students in a technological university in the Western region of Mexico that had adopted a competency-based educational model voluntarily answered a self-administered questionnaire digitalized on the Google Forms platform in the last semester of their careers. All the sample had access to the same instrument. The study was conducted in September 2022 at Tecnológico de Monterrey, Campus Guadalajara, and considers students from 10 engineering programs (biotechnology, biomedical, civil, innovation and development, industrial and systems, mechanics, mechatronics, computer technology, electronic technology, and information technology). Table 1 shows the characteristics by gender of the group.

Table 1. Participant data by gender

Male		Female		Total	
n	%	n	%	N	%
97	66%	49	34%	146	100

It is recognized that there was a significant difference in the population between men and women; however, it was proportional to the reality that occurs in Latin

American classrooms, where women have an enrollment rate in STEM careers of less than 30% [39]. Considering this was an exploratory study involving individuals, we submitted the proposal for its implementation to the interdisciplinary research group R4C for approval and regulation. We also had the technical support of the Writing Lab of the Institute for the Future of Education at Tecnologico de Monterrey.

2.2 Instrument and data analysis

For this study, the validated eComplexity instrument was applied.

The eComplexity instrument aimed to measure the participants' perception of their mastery of the reasoning-for-complexity competency and its sub-competencies. It is an instrument that has been validated theoretically and statistically by a team of experts in the field. The results obtained for the criteria evaluated by the experts were: Clarity (3.31), Coherence (3.38), and Relevance (3.54). Based on the theoretical and content validation by means of expert judgment, it was determined that the eComplexity instrument is highly valid and reliable [40]. The instrument comprised 25 items divided into four sub-competencies: Systemic, Scientific, Critical, and Innovative (or creative) Thinking. Each item was answered on a 5-level Likert scale: 1: Strongly disagree, 2: Disagree, 3: Neither agree nor disagree, 4: Agree, 5: Strongly agree (Table 2).

Table 2. eComplexity instrument items

Sub-Competencies	Item	Question
Systemic Thinking	1	I can find associations between a project's variables, conditions, and constraints.
	2	I identify data from my discipline and other areas contributing to solving problems.
	3	I participate in projects that need to be solved using inter/multidisciplinary perspectives.
	4	I organize information to solve problems.
	5	I enjoy learning different perspectives on a problem.
	6	I am inclined to use strategies to understand the parts and whole of a problem.
Scientific Thinking	7	I have the ability to identify the essential components of a problem to formulate a research question.
	8	I know the structure and formats for research reports used in my area or discipline.
	9	I identify the structure of a research article used in my area or discipline.
	10	I apply the appropriate analysis methodology to solve a research problem.
	11	I design research instruments consistent with the research method used.
	12	I formulate and test research hypotheses.
	13	I am inclined to use scientific data to analyze research problems.
Critical Thinking	14	I can critically analyze problems from different perspectives.
	15	I identify the rationale for my own and others' judgments to recognize false arguments.
	16	I self-evaluate the level of progress and achievement of my goals to make the necessary adjustments.
	17	I use reasoning based on scientific knowledge to make judgments about a problem.
	18	I make sure to review the ethical guidelines of the projects in which I participate.
	19	I appreciate criticism in the development of projects to improve them.

(Continued)

Table 2. eComplexity instrument items *(Continued)*

Sub-Competencies	Item	Question
Innovative Thinking	20	I know the criteria to determine a problem.
	21	I have the ability to identify variables from various disciplines that can help answer questions.
	22	I apply innovative solutions to diverse problems.
	23	I solve problems by interpreting data from different disciplines.
	24	I analyze research problems considering the context to create solutions.
	25	I tend to evaluate the solutions to a problem with a critical and innovative sense.

Regarding data processing, we conducted an exploratory analysis and a multivariate descriptive statistical analysis using R [41] and Rstudio [42] computational software. The exploratory analysis focused on the analysis of absolute total values, on values relative to gender expressed in percentages of complex thinking competency, and on the analysis of unidimensional dispersion in a Beeswarm chart. Statistical analysis determined arithmetic means and standard deviations and employed boxplot, principal component, and biplot analyses for each sub-competency of the complex thinking competency.

The analysis of arithmetic means was carried out to determine a representative value for the students' perception of their complex-thinking competency development and its competencies. The standard deviation analysis identified the dispersion in the perception of the competencies around the means. To complement these analyses, we created a boxplot analysis, which made it possible to visually identify data behavior patterns in the sample for each sub-competency. This tool, also known as a box and whiskers plot, allowed us to identify outliers, asymmetries, and dispersion of the data through quartiles (or percentiles). Also, to avoid collinearity problems in the multivariate analysis, we carried out a principal component analysis (PCA). This analysis makes it possible to capture the maximum variability of the original data through a new set of components (called principal components) that are independent and uncorrelated (i.e., it avoids collinearities). There are as many principal components as variables used (sub-competencies). To better understand the PCA, a Biplot analysis allowed us to visualize the relationship between variables (sub-competencies) and the behavior of the observations (students) for the two components that capture the maximum variability. Since the interest of the article was to observe the behavior of the perception of the development of sub-competencies in students, the Biplot we performed was of the form ($\alpha = 1$).

Finally, a statistical significance analysis was performed using the t-test on the difference in mean values between men and women for both the complex thinking competency and each of its sub-competencies.

3 RESULTS

The analysis of arithmetic means and standard deviations is shown in Table 3. It shows that the sample of students perceived developing complex thinking competency with a mean value of 4.32 and a standard deviation of (0.50). By gender, the men's perception of their complex thinking was higher (mean value of 4.36 compared with females' 4.24). However, the women's standard deviation was lower than the men's (0.48 and 0.51, respectively).

Regarding the total students' perception by sub-competencies, the best mean value was in the development of systemic thinking (4.47), followed by creative thinking (4.33), critical thinking (4.33), and, finally, scientific thinking (4.14). It should also be noted that systemic thinking had the lowest standard deviation (0.38), while the highest deviations were in critical thinking (0.58) and scientific thinking (0.56). Regarding the analysis by gender, the lowest mean value occurred in the perception of scientific thinking (4.21 in men and 4.02 in women).

Table 3. Complex thinking: means and standard deviations of the competency and sub-competencies by gender

Concept	Men		Women		Total	
	Mean	SD	Mean	SD	Mean	SD
Complex thinking	4.36	0.51	4.24	0.48	4.32	0.50
Scientific thinking sub-competency	4.21	0.56	4.02	0.54	4.14	0.56
Critical thinking sub-competency	4.35	0.50	4.31	0.43	4.33	0.58
Creative thinking sub-competency	4.38	0.52	4.25	0.48	4.33	0.51
Systemic thinking sub-competency	4.51	0.39	4.40	0.36	4.47	0.38

To complement the previous table, Figure 2 shows the bar chart of the mean values and deviation(s) obtained for the complex thinking competency and its sub-competencies, each color-coded according to the type of thinking. Figure 2 shows that the perception of systems thinking was the highest among the students, while scientific thinking had the lowest mean values. Similar behavior shows in the mean values for critical and creative thinking perception.

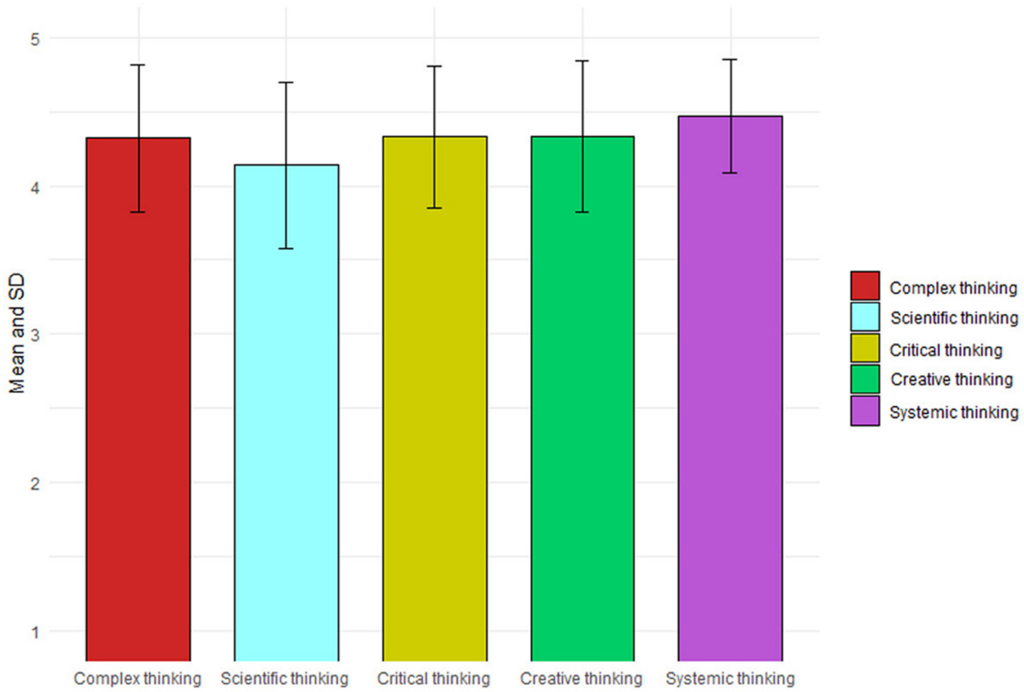

Fig. 2. Competency of complex thinking: means and standard deviations bar chart of competency and sub-competencies

Given that the bar graph analysis may hide students' behavior for the perception of developing the complex thinking competency, we present the boxplot analysis of this competency by gender (Figure 3). The figure shows that the behavior of males was more dispersed than females. That is, some male students perceived themselves to be very low in complex thinking, and others perceived themselves as highly developed. The results show that in absolute values, about 72% of the students perceived themselves as high in complex thinking (mean values of 4 to 5). At the same time, the remaining 28% perceived themselves as average (mean values of 3 to 4). By gender, 69% of males presented mean values of 4 to 5 in the perception of complex thinking, while 78% of females perceived themselves in that range.

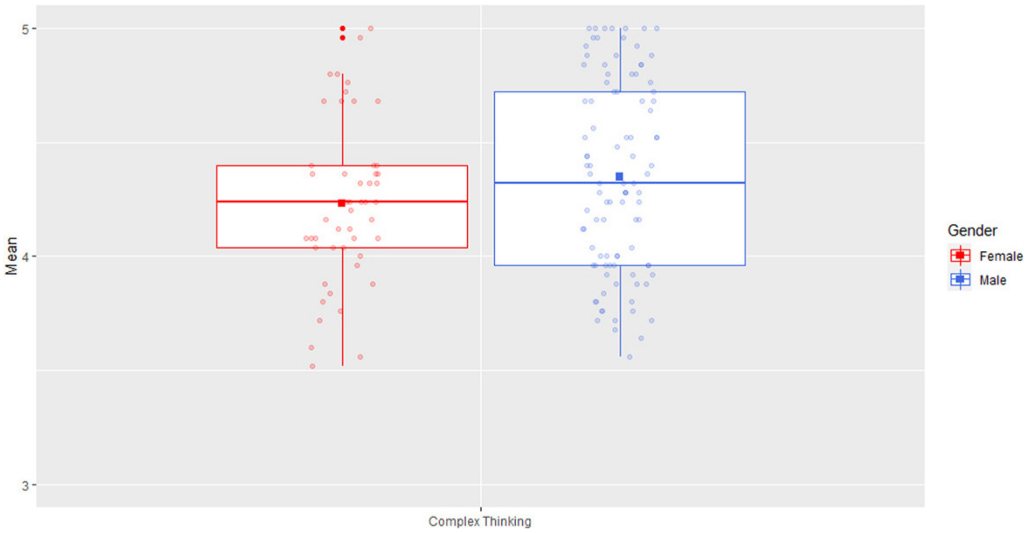

Fig. 3. Boxplot analysis: complex thinking competency by gender

Figure 4 shows a one-dimensional Beeswarm scatter plot to understand better the students' perception of the sub-competencies of complex thinking. The analysis is color-coded according to the gender of the students. The analysis shows a greater number of males with high mean values in their perception of the development of the sub-competencies (i.e., 5). On the other hand, the mean values of women range between 4 and 4.5.

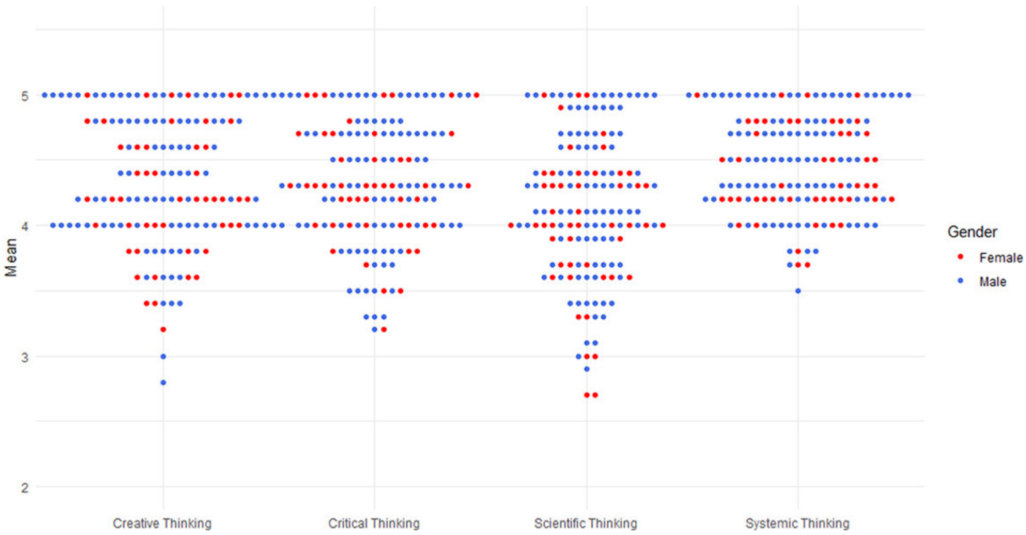

Fig. 4. Complex thinking: beeswarm analysis of sub-competencies by gender

The mean values of the students' perception of the development of the different sub-competencies of complex thinking are illustrated through the boxplot analysis (Figures 5–8). The analyses are intended to illustrate in detail students' behavior by gender in each sub-competency.

Figure 5 shows the behavior of the mean values of students' perception of developing the sub-competency of systems thinking. Males attained a higher mean value in systems thinking than females. Likewise, more male students are in the first quartile (lower mean values). On the other hand, women had a more compact behavior, i.e., less dispersed perception of complex thinking.

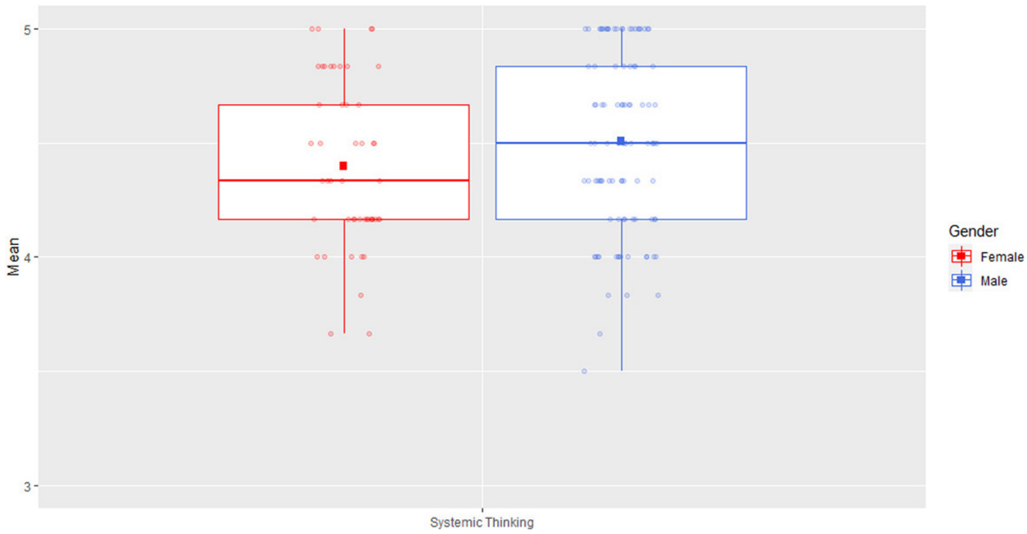

Fig. 5. Boxplot analysis of systemic thinking sub-competency by gender

The Boxplot analysis of the students' perception of critical thinking is shown in Figure 6. The figure shows significant similarities in the perception of women and men in this sub-competency. Although the men's mean in this sub-competency is higher, the analysis does not show significant gender differences.

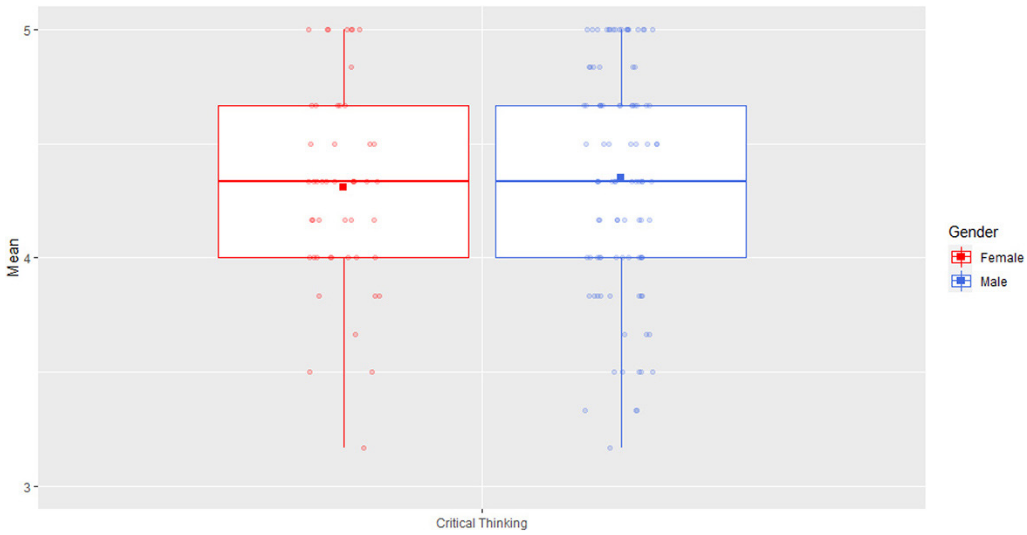

Fig. 6. Boxplot analysis: critical thinking sub-competency by gender

Regarding creative thinking, Figure 7 shows men with a higher mean value in perception than women. However, the men's dispersion is greater. Some men perceived themselves as lacking in this competency, while others felt very capable.

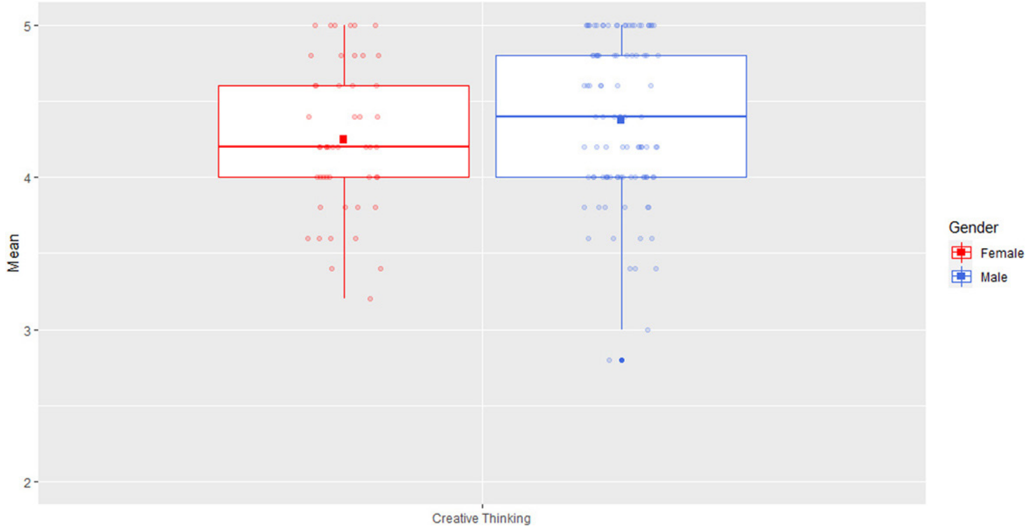

Fig. 7. Boxplot analysis: creative thinking sub-competency by gender

Regarding the analysis of perception in the development of scientific thinking, Figure 8 illustrates an asymmetry in the perception between men and women. The analysis shows men with a higher mean value in this competency than women. Likewise, women had the lowest perception of scientific thinking in the first quartile (lower mean values).

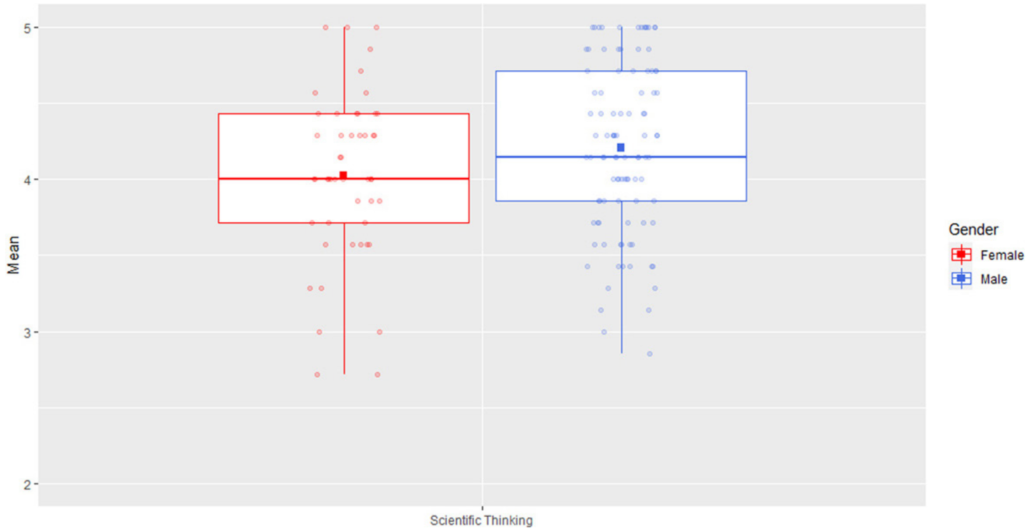

Fig. 8. Boxplot analysis: scientific thinking sub-competency by gender

The principal component analysis (PCA) performed on the students' perception of the development of complex thinking competency is illustrated in Table 4. It shows that principal component one (PC1) captured 68% of the data variability and principal component two captured 12%. Together, PC1 and PC2 represented 81.20% of the data variability. On the other hand, the analysis shows that PC1 had a high correlation with creative thinking. Thus, this component would explain the students' perception of creative and original problem-solving. On the other hand, PC2 highly correlated with critical thinking. This would explain the students' ability to evaluate and question the information provided and their ability to reason about its origin and reliability.

Table 4. Complex thinking: principle components matrix

Concept	PC1	PC2	PC3	PC4
Systemic thinking sub-competency	–0.50	–0.31	0.82	–0.23
Scientific thinking sub-competency	–0.49	–0.66	–0.26	0.49
Critical thinking sub-competency	–0.48	0.73	–0.04	0.47
Creative thinking sub-competency	–0.51	0.07	–0.49	–0.69
Standard deviation	1.65	0.71	0.64	0.58
Proportion of variance	0.68	0.12	0.10	0.09
Cumulative proportion	0.68	0.81	0.91	1.00

Based on this data, Figure 9 shows the Biplot analysis of form (α = 1) to visualize the students' data behavior without collinearities. A point represents each student. The pupils have been color-coded according to gender. The axes correspond to the principal components that capture the maximum variability (i.e., CP1 and CP2). Each sub-competency is a ray. The further away students are from the origin in the direction of a sub-competency, the higher they perceive themselves to be in that type of thinking.

On the contrary, if the students' data go opposite the direction of the sub-competency arrow, the students perceive themselves poorly developed in that type of thinking. In this sense, more men are observed in the direction of creative and systemic thinking. That is, men perceived themselves better in these sub-competencies compared with women. Similarly, many students highly perceived scientific thinking, but more women perceived themselves as low in this competency.

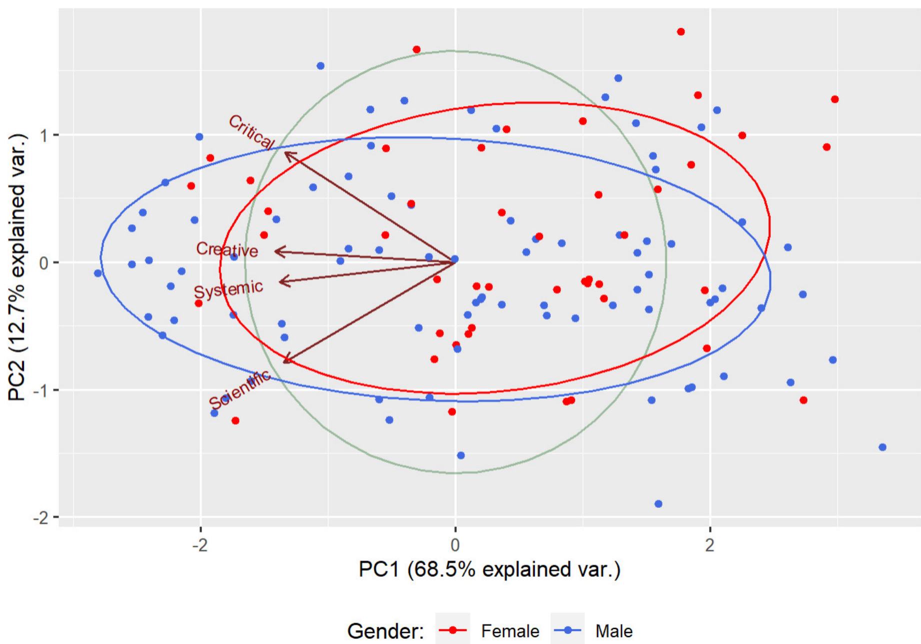

Fig. 9. Complex thinking: principal omponent Biplot explaining 81.20% of the data variability. Biplot of the form (α = 1).

Finally, Table 5 shows the analysis regarding the significance of the difference in the mean values of perceived achievement of complex thinking competence between the male and female groups. In general, it is possible to verify the existence of statistically significant differences (a *p*-value of ≤ 0.10) between men and women in terms of the complex thinking competency, although in terms of the sub-competencies, the difference in critical thinking and innovative thinking was not significant. On the other hand, the results of systematic thinking and scientific thinking do show statistically significant differences.

Table 5. Results of the significant differences between the male and female groups in the perception of achievement of complex thinking competence (student's t)

	t	df	*p* value
Complex Thinking (male and female groups)	–1.77	110.88	0.079
Systemic Thinking (male and female groups)	–1.67	102.63	0.096
Critical Thinking (male and female groups)	–0.469	108.76	0.639
Creative Thinking (male and female groups)	–1.456	103.59	0.148
Scientific Thinking (male and female groups)	–1.904	98.122	0.05

4 DISCUSSION OF RESULTS

As part of the results, the first thing analyzed was the overall data on the Complex Thinking competency, considering the gender variable. Table 3 shows that the overall result was considerably high; the means of the competency and sub-competencies exceeded 4 in all cases, i.e., the group's perceived performance level was high. It should be considered that the sample was taken from a population of students in their last semester. Thus, their formative process was close to completion, and their competencies should be close to maximum achievement. As for general results, both Table 3 and Figure 2 show that the sub-competency with the best-perceived achievement was systems thinking (4.47), followed by creative thinking (4.33) and critical thinking (4.33), and finally scientific thinking (4.14). Something interesting is that, as pointed out in the theoretical framework, scientific thinking is usually the sub-competency most associated with this discipline, primarily due to using the scientific method. However, this group had the lowest perception of achievement in this sub-competency.

Regarding gender, men presented the highest means in the competency (4.36) and all sub-competencies. Like the overall result, scientific thinking yielded the lowest means, with the women having the lowest result of the entire sample (4.02). The highest result was systems thinking among men (4.51), which is even higher than the overall average for the meta-competency (complex thinking).

To delve deeper into the data analysis, Figure 4 illustrate how the students responded, considering their gender. Figure 3 corroborates that men presented a higher mean and median than women and had the most dispersion. While there are more positive and negative results in the boxplot for men, women's data was more concentrated within the box. Figure 3 presents the value by gender relative to the overall mean of the responses to show the proportion of men and women. This graph shows no means lower than 3.00, corroborating the previous statement that the overall perception of achievement was high. On the other hand, it is interesting to note that although women presented a lower overall average than men (women 4.24 vs. men 4.36), their concentration of positive responses (above 4.00) was higher than that of their male peers (women 88% and men 69%). This situation corroborates Figure 3, where a higher concentration of very high responses (5.00) can be seen for men compared with women, influencing the fact that, despite some low responses, these did not impact the mean significantly.

In this same sense, considering the perception of achievement in the sub-competencies of complex thinking, we created the Figure 4 Beeswarm analysis to appreciate how the responses were distributed. We verified that the results by sub-competency aligned with the overall results, where most of the women's responses were in the center of the graph, in contrast to the men, who had more extreme responses, with a greater concentration in the upper part. To explore this behavior in greater depth, we conducted a specific analysis for each sub-competency.

Figure 5 presents the results of the systems thinking sub-competency, which yielded the best mean of the study (4.47). As seen in this boxplot, men not only had the highest median and mean compared with women but also, as noted in Figure 4, more high responses. Interestingly, although women had a lower mean than men (W 4.40 vs. M 4.51), they had considerable standard deviation towards positive results, although these did not attain the top of the scale. The men's mean on this indicator was not only the highest result of the sub-competencies but also exceeded the overall mean of the entire group. As noted in the theoretical framework, this result shows that the group, especially the men, perceived themselves with a high level of ability to analyze problems integratively, recognizing the multiple elements that make up a challenge [19].

Figure 6 presents the results of the critical thinking sub-competency, which, on par with innovative or creative thinking, had a mean of 4.33. Although the overall means were equal, Figures 6 and 7 allow us to appreciate that the behavior of the responses was considerably different. Figure 6 shows that the results between men and women in terms of critical thinking were quite similar (W 4.31 vs. M 4.35), which is not only evident in the means and medians, which are almost on par, but also in the general behavior of the responses, which do not show a notably different concentration in either of the two groups. Thus, it is possible to point out that both men and women in this group managed to finish their training process with a high capacity to assess the validity of reasoning, being able to analyze and evaluate the information presented to them in the face of a challenge, discerning the truth and falsity of reality, and reaching a better level of understanding of the environment when making decisions [20].

In contrast, Figure 7, innovative and creative thinking, shows significant differences between men and women in their means (W 4.25 vs. M 4.38), medians, and distribution of their responses. While it is clear that a high concentration of responses was at the top of the scale (5.00) in the men's group, the women again showed a positive concentration but tended towards their mean. Something interesting about this figure is that it clearly shows the extreme responses in the men's group since, as noted, although there was a strong concentration of responses at the top of the scale (5.00), there were also some considerably low responses. In this sense, the group managed to develop an innovative vision of the problems and challenges presented to them during their formative process, being able to visualize reality from a novel and creative approach [22].

Finally, Figure 8 presents the behavior of the scientific thinking sub-competency, which, as noted above, is the sub-competency with the lowest mean despite being an element usually associated with engineering careers. As seen in the figure, this sub-competency has the lowest means and medians compared with the other indicators, but it is also the sub-competency with the most significant difference between men and women (W 4.02 vs. M 4.21). Interestingly, the concentration of previously observed responses between men and women becomes very noticeable here; while men had many results at the top of the scale (5.00), it was almost null for women. This boxplot shows a considerable positive dispersion of responses in men, which is even noticeable in the standard deviation that tends to be above the mean. Overall, it is possible to note that the group perceived themselves as competent in using the scientific method and validating and standardizing processes when inquiring about and investigating information. However, compared with the other sub-competencies, they distinguish between feeling competent and claiming to be experts in the subject.

In the same sense, a principal-components matrix (Table 4) and a Biplot graph (Figure 9) showed in the reliability ellipses a tendency for systems thinking and creative thinking to pull the results towards these sub-competencies, which was more noticeable in men. Again, it can be seen that the men yielded less concentrated results than their female peers, showing more extreme responses at the limits of the graph compared with the women focused on the same.

Finally, in order to verify this information, a significance differences analysis (Student's t) was carried out (Table 5). In general, it was found that the differences between men and women in the complex thinking competency were statistically significant (0.079), showing that men are indeed the ones with the best results. This is also statistically proven in the case of the sub-competences of systematic thinking (0.096) and scientific thinking (0.05), although this is not the case for critical thinking (0.639) and innovative thinking (0.148).

It should be noted that the fact that there is no proof of statistically significant differences does not affect the fact that these differences exist, opening the need for more extensive studies focused on these sub-competencies in a concrete manner.

Thus, the analysis shows the response tendencies of men and women at the overall level and by sub-competencies, with men at the extremes of the scale having more presence at the top and the female responses concentrated around the middle.

Considering that the instrument measured the perception of achievement, it would be valuable to analyze why women had limited self-concepts about their capabilities, knowing themselves to be competent but not experts on the skills to meet a challenge, solve a problem, or lead a project.

In general, we conclude that this study fulfilled its objective, allowing us to identify the students' final perception of their achievement of complex thinking and valuable trends in how their perceptions were configured in the complex thinking competency and its sub-competencies.

5 CONCLUSIONS

The objective of this article was to present the results of an analysis of the level of perceived achievement of the complex thinking competency in a group of engineering students in their last semester at a university in Western Mexico. The intention was to identify whether this population had the necessary skills to meet challenges and solve problems related to the demands of their future professional environments. Specifically, we not only sought to know the level of perception of achievement but also to understand its behavior and the possible differences between the male and female populations. In conclusion, based on the results, we found sufficient data to confirm that the participants showed a high level of perception of achieving the competency of complex thinking, which was more noticeable in the male population.

It is recognized that the present study could be limited by its purely descriptive methodology; however, considering the objective set, we consider that the results are sufficient and valuable and fulfill the intention of this work. Furthermore, we recognize that this is an exploratory study, which implies that it is not exhaustive but instead sheds light on a possible area of study to deepen the relationship between engineering education and developing complex thinking. In a practical sense, this article invites to deepen this relationship with a gender perspective because although our results show statistically significant differences between men and women occuring in only 2 of the 4 subcompetencies, this implies the need to expand the sample to verify these results.

This article raises an attractive area of opportunity for educational institutions with engineering careers. They are invited to pay attention to how they promote complex thinking as part of their graduation competencies. In addition, this article highlights the need to address the gender gap that historically exists in these disciplines, which, although it has been reduced, is still present.

6 ACKNOWLEDGMENT

The authors acknowledge the technical support of Writing Lab, Institute for the Future of Education, Tecnologico de Monterrey, Mexico, in the production of this work. We acknowledge as well the support of the Center for Linkage and Professional Development, Tecnologico de Monterrey, Campus Guadalajara.

7 FUNDING

This paper is a product of the project “EduToolkit: innovation with artificial intelligence for the development of social entrepreneurship, innovation and complex thinking skills”, with funding from NOVUS 2021 y 2022 Fund, with ID Number 206 and 268. Likewise, the authors acknowledge the financial support from Tecnologico de Monterrey through the “Challenge-Based Research Funding Program 2022”. Projects ID # I001 – IFE001 – C1-T1 – E, ID # I003 – IFE001 – C2-T3 – T, ID# I004 – IFE001 – C2-T3 – T and ID # I005 – IFE001 – C2-T3 – T.

8 REFERENCES

[1] S. Riahi. Strengthening the teaching of soft skills in the pedagogical architecture of Moroccan universities. International Journal of Engineering Pedagogy (iJEP), vol. 12, no. 4, pp. 47–62, 2022. https://doi.org/10.3991/ijep.v12i4.22329

[2] Tecnologico de Monterrey, “Razonamiento para la complejidad,” in *Tecnologico de Monterrey, Competencias Transversales. Una visión desde el modelo educativo Tec21*, Monterrey, Nuevo Leon, Mexico: Tecnologico de Monterrey, pp. 62–76, 2019.

[3] D. Artha, D. Sulisworo, J. Jumandi, and E. Istiyono, "STEM ISCIT Learning tools to improve integrative scientific thinking," *IRIP Indones. Rev. Phys.*, vol. 4, no. 2, pp. 32–37, 2021, http://journal2.uad.ac.id/index.php/irip/article/view/5265

[4] A. AlMunifi and A. Aleyani. Knowledge and skills level of graduate civil engineers employers and graduates' perceptions. International Journal of Engineering Pedagogy (iJEP), vol. 9, no. 1, pp. 84–101, 2019. https://doi.org/10.3991/ijep.v9i1.9744

[5] N. Almetov, A. Zhorabekova, I. Sagdullayev, Z. Abihairova, and K. Tulenova. Engineering education: problems of modernization in the context of a competence approach. International Journal of Engineering Pedagogy (iJEP), vol. 10, no. 6, pp. 7–20, 2020. https://doi.org/10.3991/ijep.v10i6.14043

[6] A. Aleryani and A. AlMunifi. A roadmap to the development of key competencies of engineering and technology graduates. International Journal of Engineering Pedagogy (iJEP), vol. 9, no. 5, pp. 75–88, 2019. https://doi.org/10.3991/ijep.v9i5.11094

[7] A. Valencia, "Brief history of engineering," *Fac. Eng. Mag.*, vol. 20, no. 1, pp. 119–136, 2000.

[8] M. Vargas, "The current state of engineering education. Criteria for excellence and competitiveness. ANUIES," 2022. (in Spanish) http://publicaciones.anuies.mx/pdfs/revista/Revista94_S1A2ES.pdf (accessed Sep. 15, 2022).

[9] J. Dettmer González, "Engineering education in the XXI century," *Rev. Panam. Pedagog.*, no. 5, Jan. 2004, (in Spanish) https://doi.org/10.21555/rpp.v0i5.1867

[10] L. Vega, "Engineering education in the global context: a proposal for engineering education in the first quarter of the 21st century," *Ing. Investig. y Tecnol.*, vol. 14, no. 2, pp. 177–190, 2013.

[11] M. Álvarez and C. Gracía, "Training trends in Mexico," in *Engineering education, innovation and technological development in Iberoamerica. Trends in engineering education in Iberoamerica*, Mexico: Arfo Editores e Impresores Ltda, 2014.

[12] N. Saienko, Y. Olizko, and A. Cunha. Perceptions of fostering creative thinking skills in ESP classrooms in Ukraine and Portugal. International Journal of Engineering Pedagogy (iJEP), vol. 11. no. 4, pp. 23–41, 2021. https://doi.org/10.3991/ijep.v11i4.20129

[13] M. Pinho-Lopes and J. Macedo. Project-based learning to promote high order thinking and problem solving skills in geotechnical courses. International Journal of Engineering Pedagogy (iJEP), vol. 4, no. 5, pp. 20–27, 2014. https://doi.org/10.3991/ijep.v4i5.3535

[14] H. Alley, "Scientific thinking: get the results you want," *Canada's Ind. journal. Plant.*, vol. 79, no. 3, p. 20, 2020.

[15] Tecnologico de Monterrey, "Reasoning for complexity. In Tecnologico de Monterrey, Transversal Competencies.," *A Vis. from Educ. Model Tec21*, pp. 62–76, 2019.

[16] E. Morin, *Introduction to complex thinking*. Ciudad de México, México: Gedisa, 1990.

[17] M. Nagahi, R. Jaradat, S. Davarzani, M. Nagahisarchoghaei, and S. Goerger, "Academic performance of engineering students." https://doi.org/10.18260/1-2--34084

[18] A. A. M. Jaaron and C. J. Backhouse, "Operationalisation of service innovation: a systems thinking approach," *Serv. Ind. J.*, vol. 38, no. 9–10, pp. 561–583, Jul. 2018, https://doi.org/10.1080/02642069.2017.1411480

[19] S. Koerber and C. Osterhaus, "Individual differences in early scientific thinking: assessment, cognitive influences, and their relevance for science learning," *J. Cogn. Dev.*, vol. 20, no. 4, pp. 510–533, Aug. 2019, https://doi.org/10.1080/15248372.2019.1620232

[20] L. Cui, Y. Zhu, J. Qu, L. Tie, Z. Wang, and B. Qu, "Psychometric properties of the critical thinking disposition assessment test amongst medical students in China: a cross-sectional study," *BMC Med. Educ.*, vol. 21, no. 1, p. 10, Dec. 2021, https://doi.org/10.1186/s12909-020-02437-2

[21] C. Ossa-Cornejo, M. Palma-Luengo, N. Lagos-San Martín, and C. Díaz-Larenas, "Evaluación del pensamiento crítico y científico en estudiantes de pedagogía de una universidad chilena," *Rev. Electrónica Educ.*, vol. 22, no. 2, p. 1, Mar. 2018, https://doi.org/10.15359/ree.22-2.12

[22] N. Lettry and R. L. Echegaray, "Organizational change from innovation and complexity," 2020. [Online]. Available (in Spanish): https://bdigital.uncu.edu.ar/fichas.php?idobjeto=15475

[23] A. Gribnicow, "Development of competencies for the management of cultural enterprises and the development of creative industries in the Ibero-American context," 2020. https://oei.int/downloads/disk/eyJfcmFpbHMiOnsibWVzc2FnZSI6IkJBaDdDRG9JYTJWNVNTSWh-kemt4ZEhrNGVuTjRlVGQ2ZURKb1oyYzBNRGQ2ZDJSeGFuSmhOd1k2QmtWVU9oQmthWE53YjNOcGRHbHZia2tpWkdsdWJHbHVaVHNnWm1sc1pXNWhiV1U5SWtsT1JrOVNUVVVnUVU1RVVrVlRJRVpKVGtGTUxuQmtaaUk3SUdacGJHVnZVzFsS2oxVlZFWXRPQ2NuU1U1R1QxSk5SU1V5TUVGT1JGSWxRek1sT0RsVEpUSXd-Sa2xPUVV3dWNHUm1CanNHVkRvUlkyOXVkR1Z1ZEY5MGVYQmxTU0lVWVhCd2JHbGpZWFJwYjI0dmNHUm1CanNHVkE9PSIsImV4cCI6IjIwMjMtMDMtMzBUMTc6MzQ6MzQuNTAwWiIsInB1ciI6ImJsb2Jfa2V5In19--075ae23e7c063bdad0f39f15a5ac63202d4290f3/INFORME%20ANDR%C3%89S%20FINAL.pdf?content_type=application%2Fpdf&disposition=inline%3B+filename%3D%22INFORME+ANDRES+FINAL.pdf%22%3B+filename%2A%3DUTF-8%27%27INFORME%2520ANDR%25C3%2589S%2520FINAL.pdf (accessed Sep. 15, 2022).

[24] N. Kurmanov, Z. Aliyeva, G. Kabdullina, and L. Mutaliyeva, "Digital entrepreneurship competencies among students: methodological aspects of the maturity level and development program making," *J. Entrep. Educ.*, vol. 23, no. 2, pp. 1–11, 2020, [Online]. Available: https://www.abacademies.org/articles/digital-entrepreneurship-competencies-among-students-methodological-aspects-of-the-maturity-level-and-development-program-making-9046.html

[25] M. J. Sousa and J. M. Costa, "Discovering entrepreneurship competencies through problem-based learning in higher education students," *Educ. Sci.*, vol. 12, no. 3, p. 185, Mar. 2022, https://doi.org/10.3390/educsci12030185

[26] V. Azurín, "Development of critical thinking and its effects on the writing of argumentative texts of students of the fourth cycle of the faculty of social sciences and humanities of the national university of education Enrique Guzman y Valle.," Universidad Nacional de Educación. Lima, Perú., 2018. [Online]. Available (in Spanish): https://repositorio.une.edu.pe/bitstream/handle/20.500.14039/1699/TDCE1797A1-AzurinCastillo.pdf?sequence=1&isAllowed=y

[27] S. Eyzaguirre, "The role of philosophy in the development of critical thinking," *Puntos Ref.*, no. 485, pp. 1–8, 2018, [Online]. Available (in Spanish): https://educacion.udd.cl/files/2018/08/El-rol-de-la-filosofia-en-el-desarrollo-del-pensamiento-crítico.pdf

[28] P. Gutiérrez, K., and Medina, "Reflective critical thinking: essential competence in the training of the architect.," *Maest. y Soc.*, vol. 18, no. 1, pp. 199–216, 2021, [Online]. Available (in Spanish): https://maestroysociedad.uo.edu.cu/index.php/MyS/article/view/5328/4922

[29] J. Cardozo, "Contributions of systems thinking to corporate social responsibility strategy," EAN University. Bogotá, Colombia., 2020. [Online]. Available: https://repository.universidadean.edu.co/bitstream/handle/10882/10087/CardozoJohan2020.pdf?sequence=1&isAllowed=y

[30] A. León, G. Barrios, J. del Carmen, F. Arevalo, A. Rincón, and A. Pérez, "The development of systematic thinking conducive to intelligent organizations," *Iberoam. Ciencias*, vol. 6, no. 5, pp. 52–61, 2019, [Online]. Available (in Spanish): http://www.reibci.org/publicados/2019/dic/3800114.pdf

[31] C. Mendoza, "Systemic thinking in the management of organizations," Universidad Militar Nueva Granada, 2018. [Online]. Available (in Spanish): https://repository.unimilitar.edu.co/bitstream/handle/10654/17568/MendozaMezaCesarOctavio2018.pdf.pdf?sequence=1&isAllowed=y

[32] E. M. Paredes, "Critical thinking in university students," *Norte Med.*, vol. I, no. 1, pp. 1–5, 2021.

[33] S. Ruidiaz, "Influence of the pedagogical proposal with STEM approach in the development of scientific thinking from the chemistry class of the students of grade 1101 of the IED Francisco Olaya," Los Andes University, 2021. [Online]. Available (in Spanish): https://repositorio.uniandes.edu.co/handle/1992/53039?show=full

[34] B. E. C. Arenas and J. E. C. de Adrianza, "Medicine in Venezuela, technological innovations and moral capital," *Opción Rev. Ciencias Humanas y Soc.*, no. 86, pp. 924–958, 2018.

[35] E. Rojas-Mancilla and M. E. Cortés, "Linking scientific research with undergraduate training in health careers," *Rev. Med. Chil.*, vol. 145, no. 4, pp. 549–550, Apr. 2017, (in Spanish) https://doi.org/10.4067/S0034-98872017000400017

[36] A. Vázquez and M. Manassero, "Beyond scientific understanding: science education to develop thinking.," *Rev. Electrónica Enseñanza las Ciencias*, vol. 17, no. 2, pp. 309–336, 2018.

[37] J. Chamizo, *Scientific thinking skills*. Mexico City: Universidad Nacional Autónoma de México, UNAM. Facultad de Química., 2017. [Online]. Available (in Spanish): http://www.joseantoniochamizo.com/pdf/educacion/libros/014_Habilidades_pensamiento_cientifico.pdf

[38] J. C. Vázquez-Parra, I. M. Castillo-Martínez, M. S. Ramírez-Montoya, and A. Millán, "Development of the perception of achievement of complex thinking: a disciplinary approach in a latin american student population," *Educ. Sci.*, vol. 12, no. 5, p. 289, Apr. 2022, https://doi.org/10.3390/educsci12050289

[39] F. G. Arredondo Trapero, J. C. Vázquez Parra, and L. M. Velázquez Sánchez, "STEM y Brecha de Género en Latinoamérica," *Rev. El Col. San Luis*, no. 18, pp. 137–158, Apr. 2019, https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1665-899X2019000100137

[40] I. M. Castillo-Martínez, M. S. Ramírez-Montoya, and G. Torres-Delgado, "Reasoning for complexity competency instrument (e-Complexity): content validation and expert judgment. Education in the knowledge society," *Educ. Knowl. Soc.*, vol. (In evaluation, 2022).

[41] R Core Team, "A language and environment for statistical computing." R Foundation for Statistical Computing, Vienna, Austria, 2017. [Online]. Available: https://www.r-project.org/

[42] RStudio Team, "RStudio: Integrated Development for R." RStudio, PBC, Boston, MA, 2022. [Online]. Available: http://www.rstudio.com/

9 AUTHORS

Marco Cruz-Sandoval PhD in Sustainability from the Universitat Politécnica de Catalunya-BarcelonaTech at the University Research Institute for Sustainability Science and Technology. He is currently a postdoctoral researcher at the Center for the Future of Cities at Tecnologico de Monterrey (Mexico). His research has focused on the fulfillment of the Sustainable Development Goals (SDGs) of the United Nations on the subjects of resilient and sustainable cities—mainly on social, environmental, and spatial justice issues. Among the main achievements of his research stands out the introduction of the Compositional Data Analysis (CoDa) method in the literature specialized in multivariate statistical analysis of urban phenomena. (email: cruzsandovalmarco@tec.mx).

José Carlos Vázquez-Parra PhD in Humanistic Studies with a specialisation in Ethics from the Tecnológico de Monterrey. He is currently Research Professor in the Department of Humanistic Studies of the School of Humanities and Education at the Tecnológico de Monterrey Campus Guadalajara. His research interests are LGBTIQA Studies, Gender Studies, Economic Ethics and Educational Innovation. He has more than 100 articles published in journals in more than 20 countries. He has carried out several studies on the development of transversal competences in the university environment. (email: jcvazquezp@tec.mx).

Martina Carlos-Arroyo PhD in Social Sciences and Master in Education, as well as a Bachelor of Psychology. Currently doing a Postdoctoral Stay at the Institute for the Future of Education Campus Guadalajara. Her lines of research are Gender Studies, Science, Educational Innovation and Social Imaginaries. Member of the Mexican Network of Science, Technology and Gender, AC. (CITEG Network, A.C.). Multiple publication of articles and book chapters with different educational institutions. (email: martina.carlos@tec.mx).

Marco Vinicio del Angel-González Professional with experience in educational transformation and management. Experience in talent attraction, development and learning plans for individuals and teams. Attraction and development areas to connect opportunities with the best talent in Mexico (email: marco.delangel@tec.mx).