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Complex Thinking as an Enabler of Scientific Entrepreneurship: Self-Assessment in Guatemalan Higher Education

Pensamiento complejo como habilitador del emprendimiento científico: autovaloración desde la educación superior en Guatemala

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ABSTRACT
This study analyzes the self-assessment of complex thinking involved in the development of scientific entrepreneurial skills among students at the Universidad of San Carlos of Guatemala, who participated in the extracurricular workshop "Scientific Entrepreneurship with a Vision of the Future." This program specializes in strengthening students‘ prototyping and communication skills for entrepreneurship projects through an educational platform. The intervention engaged 127 university students and was implemented in four methodological stages: identification, design, development, and dissemination. To measure the students‘ self-assessment of skills, the *ecomplexCE* questionnaire was designed, validated, and employed to measure students‘ scientific, critical, systemic, and innovative thinking. This Likert-scale instrument was applied before and after the workshop. The results showed an improvement in students‘ perception of entrepreneurial skills between the pre-test and the post-test, although the differences were not statistically significant. It was concluded that the development of complex thinking skills can enhance scientific entrepreneurship and that the design of training experiences facilitated by learning platforms can positively impact students' self-assessment of their entrepreneurial skills.

RESUMEN
Este estudio analiza la autovaloración del pensamiento complejo enfocado en el desarrollo de habilidades de emprendimiento científico en estudiantes de la Universidad San Carlos de Guatemala, quienes participaron en el taller extracurricular Emprendimiento Científico con Visión de Futuro. Este programa se especializa en fortalecer competencias para la creación de prototipos y la comunicación de proyectos de emprendimiento mediante una plataforma educativa. La intervención incluyó a 127 universitarios y se estructuró en cuatro etapas metodológicas: identificar, idear, inventar e informar. Para evaluar la autovaloración de las habilidades, se utilizó el cuestionario ecomplexCE con escala Likert, diseñado y validado para medir el pensamiento científico, crítico, sistémico e innovador. Este instrumento se aplicó antes y después del taller. Los resultados mostraron una mejora en la percepción de las habilidades emprendedoras entre el pretest y el postest, aunque las diferencias no fueron estadísticamente significativas. Se concluye que el desarrollo de competencias de pensamiento complejo puede fortalecer el emprendimiento científico y que el diseño de experiencias formativas, acompañadas por el uso de plataformas de aprendizaje, puede influir positivamente en la autovaloración de las habilidades emprendedoras de los estudiantes.

KEYWORDS · PALABRAS CLAVES
Complex thinking, scientific entrepreneurship, educational innovation, higher education.
Pensamiento complejo; emprendimiento científico; innovación educativa; educación superior

1. Introduction

Entrepreneurship requires the ability to create value through initiative, innovation, and problem-solving (Abebe, 2023). It extends beyond merely creating new companies to developing entrepreneurial skills in university students, such as critical thinking, creativity, and innovation (Wurth et al., 2022). Moreover, *scientific* entrepreneurship involves applying knowledge to generate innovative solutions (Cardella et al. 2020).

In higher education, the topic of entrepreneurship is most often associated with the business environment (Piñeiro-Chousa et al., 2020; Surana et al., 2020). However, it is essential to note that this is a transversal topic for all disciplines: Students must acquire the necessary skills during their training to identify opportunities, develop innovative projects, and solve complex problems (Virzi et al., 2015; Chepurenko et al., 2019).

Education for entrepreneurship, as a scientific field, is a continuously expanding area of research (Pastran, 2021). However, the interconnection between the application of science and entrepreneurial communities (Lansdtröm et al., 2022) is primarily limited to collaboration among researchers rather than the training of students (Blankesteijn et al., 2021). Therefore, it is essential to promote closer integration between research and teaching in entrepreneurship, facilitating the transfer of knowledge and skills from the scientific field to the classroom (Duval-Couetil et al., 2021), which could potentially increase the innovative and entrepreneurial capacity of students (Filser et al., 2019).

This study focused on the self-assessment of scientific entrepreneurship skills in Guatemalan university students who participated in a workshop mediated by a digital platform. The objective was to evaluate the impact of the workshop on their self-assessment of entrepreneurial skills and determine the effectiveness of the digital platform in entrepreneurship training. The research question that guided this study was: How does an entrepreneurship workshop mediated by a digital platform influence the self-assessment of entrepreneurial skills of university students in Guatemala?

2. Theoretical framework

2.1 Entrepreneurship in Higher Education

Constant changes in professional life necessitate that university students in training develop skills to navigate working life more efficiently (Arevalo et al., 2022). One of these skills is related to learning entrepreneurship and growing entrepreneurial ecosystems in universities; these ecosystems provide students with the necessary resources to transform innovative ideas into viable projects (Thomas et al., 2021). Additionally, they promote collaboration among academia, industry, and government, which facilitates access to financing and other essential support for entrepreneurial development (Gicheva & Link, 2022).

Among the skills that must be developed to learn entrepreneurship are the capacities, skills, abilities, and aptitudes necessary for ventures, which can be acquired through training and training processes (Fernández et al., 2022). These include identifying and seizing opportunities, creativity and innovation, resource management, and resilience after failure (Wang et al., 2023). In addition, it is essential to develop interpersonal skills such as teamwork, effective communication, and leadership (Harrison, 2023), which are vital to entrepreneurial success (Bahena-Álvarez et al., 2019).

Graduates who lack these skills will face more laboral challenges because they will be unable to adapt to an ever-changing, highly competitive market (Boyd, 2022). The lack of entrepreneurial skills can limit their employment opportunities and hinder their ability to grow within their professional disciplines (de Oca Rojas et al., 2022). On the contrary, those who possess these skills will be better equipped to create their own challenges and make significant contributions to innovation, scientific research, and society as a whole (Jiang & Hou, 2019).

2.2 Entrepreneurship and development of scientific skills

Entrepreneurship and the development of scientific skills are intrinsically linked, as both require the cultivation of creativity, innovation, and problem-solving skills (Silva et al., 2024). Educational programs that integrate entrepreneurship into training should promote a science-based mindset and knowledge development (Fini et al., 2022), as this facilitates the identification of opportunities and the application of scientific knowledge in creating innovative solutions (Zhang et al., 2024).

Some studies have shown that entrepreneurial skills also generate scientific training skills (Baker, 2022); thus, entrepreneurship can be considered a universal competency with scientific traits that students should develop during their university education (Baena-Luna et al., 2020). This competency not only increases the employability of graduates but also fosters greater adaptability and resilience in a changing work environment (Cardella et al., 2021).

On the other hand, entrepreneurship training within scientific disciplines is effective in strengthening transversal skills, such as communication, teamwork, and leadership, which are essential for success in both business and academia (Boyle & Dwyer, 2021). Training programs that combine theory and practice have been successfully implemented in several universities, yielding positive results in preparing students to address the complex challenges that emerge in their disciplines (Diez et al., 2022).

In this way, scientific entrepreneurship fosters a culture of interdisciplinary collaboration, allowing students to work more effectively with experts from other disciplines to develop joint projects (Cheng, 2022). This collaboration not only enriches the learning process but also improves the quality and impact of research results (Azqueta et al., 2023; Zhang, 2022). Several studies have demonstrated the importance of adopting collaborative approaches to technology transfer and the commercialization of scientific innovations (Muñoz & Dimov, 2023).

The integration of entrepreneurship with a scientific approach not only benefits students and academic institutions but also significantly impacts the economy and society in general (Cunningham & Menter, 2021), promoting a mindset that can lead to the emergence of ideas, prototypes, research projects, the development of innovative solutions to social problems, and the emergence of innovative ecosystems (Niu et al., 2019).

2.3 Complex thinking: a competency that triggers scientific entrepreneurship

Complex thinking is a transversal competency that can enrich scientific entrepreneurship (Sułkowski et al., 2020). This macro-competency comprises the sub-competencies of critical, systemic, scientific, and innovative thinking in educational environments (Cruz-Sandoval et al., 2023). Its development equips students to analyze problems from multiple perspectives, identify patterns, apply the scientific method to validate hypotheses, and generate evidence-based solutions (Vázquez-Parra et al., 2025). Additionally, it fosters creativity and innovation, promoting the generation of ideas and products that address market and societal needs (Calanchez Urribarri, 2022). In the context of scientific entrepreneurship, these skills are crucial for transforming knowledge into viable and sustainable proposals, thereby promoting the development of innovative solutions that contribute to technological and social progress (López-Caudana et al., 2025).

The incorporation of complex thinking as a trigger for entrepreneurship prepares students to approach problems holistically, integrating knowledge from various disciplines to face challenges with a structured yet flexible vision (Cruz-Sandoval et al., 2023). Not only does it strengthen their training in their respective areas of study, but it also equips them with essential skills to lead projects in a globalized, continuously evolving environment (Farida et al., 2022). In this sense, higher education should promote teaching strategies that foster the development of complex thinking, providing methodological and technological tools that enable students to develop entrepreneurial skills comprehensively (Suárez-Brito et al., 2024). Entrepreneurial training based on complex thinking enhances the ability of future professionals to innovate, fostering dynamic entrepreneurial ecosystems where the interconnection between academia, industry, and society drives the creation of applied knowledge and the development of sustainable solutions to contemporary problems (Alvarez-Icaza et al., 2024).

3. Methodology

The study employed a quantitative research approach to evaluate students' self-assessments of scientific entrepreneurship skills from the perspective of complex thinking. Its design was quasi-experimental with pre- and post-intervention measurements but did not include a control group (Manterola & Otzen, 2015). The choice of this design was due to the nature of the intervention, as the workshop was offered as an open-access training experience for all interested students, making it impossible to assign participants to experimental and control groups randomly. Additionally, the research aimed to minimize potential ethical biases by ensuring that all students had the opportunity to benefit from training in scientific entrepreneurship. Although the absence of a control group limited the possibility of establishing a direct causal relationship between the intervention and changes in the students' self-assessment of skills, the pre-post design made it possible to observe trends and evaluate the perceived impact of the workshop on developing entrepreneurial competencies (Althubaiti & Althubaiti, 2024).3.1 Participants

The study employed non-probabilistic convenience sampling (Novielli et al., 2023; Shi & Cheung, 2024). University students enrolled in various educational programs at the Faculty of Humanities (FH) and the School of Secondary Education Teacher Training (EFPEM) at the San Carlos University of Guatemala were invited to participate in an extracurricular training experience called "Scientific Entrepreneurship with a Vision of the

Future." One hundred twenty-seven university students participated in April 2024. The gender composition was 79.53% women and 20.47% men. Table 1 presents the participation percentages.

Table 1

Sample composition by educational program.

Faculty	Educational Program	n	%	W	M
FH	Bachelor's in Pedagogy and Educational Research	37	29.13	31	6
	Bachelor's in Pedagogy and Curricular Planning	22	17.3	19	3
EFPEM	Bachelor's in Mathematics and Physics Teaching	42	33.1	34	8
	Secondary Education Teaching in Computing and Informatics	26	20.47	17	9
	Total	**127**	**100**	**101 (79.53 %)**	**26 (20.47 %)**

Source: own elaboration.

3.2 Ethics

All information provided by participants was collected with their consent (https://comiteinstitucionaletica.tec.mx/es/formatos). The implementation was regulated and approved by the Tecnologico de Monterrey Ethics Committee (IFE-2024-001) and supervised by the interdisciplinary research group R4C, with technical support from the Writing Lab of the Institute for the Future of Education at Tecnologico de Monterrey, Mexico. All the information recovered was protected under the criteria established in the "Federal Law on the Protection of Personal Data in Possession of Private Parties," which is in force in Mexico. In addition, to guarantee the participants' confidentiality and comply with the ethical research principles, the database constructed was completely anonymized before its analysis, eliminating any information that could identify the students.

3.3 Design and implementation of the workshop

The workshop's instructional design had four stages: identify, innovate, invent, and inform. It was explicitly designed to create innovative and effective educational experiences. The workshop content was structured in four main topics that aligned with the stages above. Each topic was linked to specific practices designed to develop entrepreneurial skills, including selecting literature in digital environments to identify entrepreneurship opportunities, ideating viable projects, making low-level prototypes, and developing effective communication skills. Table 2 shows the syllabus.

Table 2

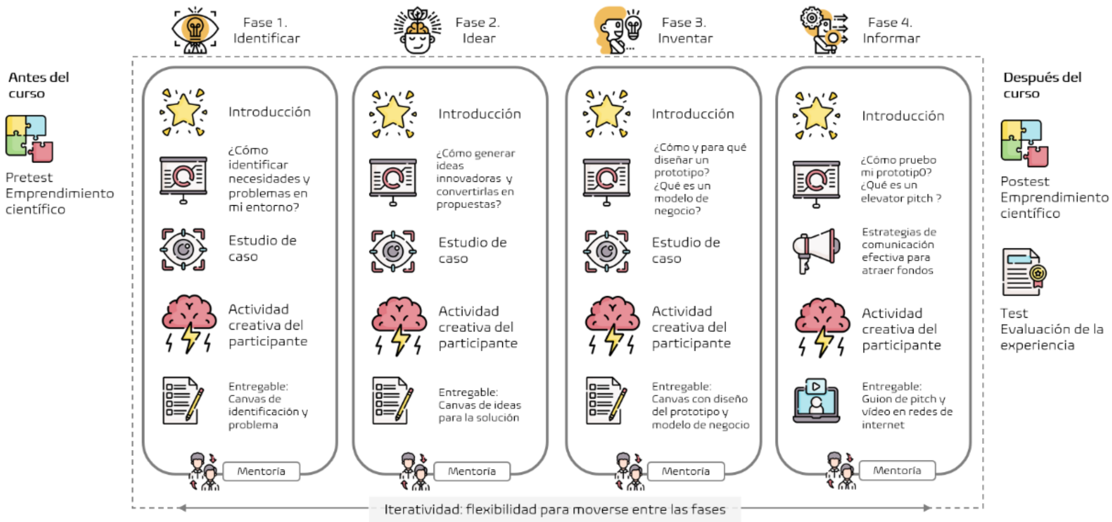
Organization of workshop topics

Instructional Design Stage	Topic	Skills	Purpose
Identify	Detecting science-based entrepreneurial opportunities	Identification of market needs and innovation opportunities.	Equip students with the skills to identify opportunities for scientific entrepreneurship, recognizing areas where science can be applied to solve real problems.
Ideate	Formulation of viable ideas that can become a science-based venture.	Creativity to propose disruptive solutions in existing markets or create new markets.	Foster the ability to devise innovative solutions that leverage scientific knowledge to create sustainable and profitable projects.
Invent	Development of scientific products and services, along with an outline of a business model.	Application of scientific and technological principles in the development of products or services. Comprehension of a business model.	Teach students how to transform ideas into tangible products or services by efficiently utilizing technological and scientific resources.
Inform	Communication strategies to disseminate entrepreneurship projects.	Effective communication techniques to promote scientific and technological products.	Train students to communicate the value of their scientific endeavors to potential investors, customers, and partners, thereby maximizing their chances of success.

Each topic incorporated open educational resources, such as documents, videos, and audio files, as well as digital tools and artificial intelligence applications designed to generate and analyze texts. A deliverable was requested for each topic. The workshop was organized in four synchronous sessions and was implemented in April 2024. Figure 1 illustrates the workshop's structure.

Figure 1

Structure and interaction of the workshop



Source: Own elaboration

3.4 Instrument

The employed instrument was a questionnaire called *ecomplex-CE,* which aimed to measure the students' self-assessment of scientific entrepreneurship skills from the perspective of complex thinking. Its Likert-type scale had four response options: 1) strongly disagree, 2) disagree, 3) agree, and 4) strongly agree. Fifteen experts in educational sciences and entrepreneurship had previously validated it, obtaining an overall Aiken's V reliability of 0.8846, which can be considered high (Merino-Soto, 2023). Table 3 shows the instrument's specifications.

Table 3

Complex thinking dimensions and items of the ecomplex-CE instrument

Complex thinking dimension	Variables	Items
Systemic thinking	Technical knowledge and experience in the field	E1. I possess the necessary disciplinary knowledge to participate in a scientific entrepreneurship project.
		E2. I have experience collaborating on and leading scientific entrepreneurship projects.
		E3. My professional background enables me to make effective contributions to scientific entrepreneurship projects.
	Technology trend analysis and market understanding	E4. I can identify reliable information sources to analyze technological trends relevant to entrepreneurship.
		E5. I can identify and understand related technology trends that can effectively address societal needs.
		E6. I can select the most suitable technological trend to integrate into my scientific entrepreneurship project from among various options.
Scientific thinking	Development of products/services based on technology	E7. My experience in developing innovative services based on science and technology enables me to make significant contributions to entrepreneurial projects.
		E8. I can lead the development of products based on science and technology
		E9. I can generate ideas for scientific entrepreneurship that address specific challenges in the scientific and technological fields.
	Management and protection of intellectual property	E10. I can distinguish what can be registered as intellectual property and what cannot.
		E11. I am familiar with the procedures for registering intellectual property.
		E12. I can develop effective strategies to register the intellectual property of different components of a scientific endeavor
Critical thinking	Agile and lean design methodologies	E13. I can manage and complete the stages of a scientific undertaking with short deadlines.
		E14. I can coordinate and synchronize team tasks to develop project stages efficiently.
		E15. I have experience with project segmentation and can adapt scientific ventures dynamically to meet emerging needs.
	Growth Hacking	E16. I can design resource optimization strategies that increase user volume, revenue, or project impact with minimal expense and effort.

Complex thinking dimension	Variables	Items
		E17. I have experience in applying analytical methodologies to examine user and market behavior data to develop effective growth strategies.
		E18. I can look for out-of-the-ordinary solutions to the most common challenges
Innovative thinking	User Experience Design	E19. I can find innovative and unconventional solutions to the most frequent challenges.
		E20. I have a background in integrating user experience principles to develop innovative products and services in scientific entrepreneurship.
	Decision-making	E21. I can identify and execute strategic decisions that potentiate growth and sustainability in scientific ventures.
		E22. I can use complex problem-solving techniques to make critical decisions for the development of scientific and technological projects.

Cronbach's α was used to analyze the questionnaire's reliability, yielding an overall α of 0.9503 in the pre-test and 0.9525 in the post-test, which indicates excellent reliability (Luh, 2024). An internal consistency analysis was performed for the pretest. The results yielded the Pearson correlations shown in Table 4, where a p-value of 0.000 represents strong positive relationships; the four types of thinking had coefficients ranging from 0.722 to 0.804. The Cronbach α values ranged from 0.8272 to 0.8702, reflecting good internal consistency for each scale.

Table 4

Instrument reliability analysis in the post-test

		Systemic Thinking	Scientific Thinking	Critical Thinking	Innovative Thinking	Cronbach's α
Systemic Thinking	Pearson correlation	1	.739**	.735**	.722**	.8702
	Sig. (two-tailed)		.000	.000	.000	
Scientific Thinking	Pearson correlation	.739**	1	.758**	.746**	.8410
	Sig. (two-tailed)	.000		.000	.000	
Critical Thinking	Correlación de Pearson	.735**	.758**	1	.804**	.8272
	Sig. (two-tailed)	.000	.000		.000	
Innovative Thinking	Correlación de Pearson	0.722**	0.746**	.804**	1	.8600
	Sig. (two-tailed)	.000	.000	.000		

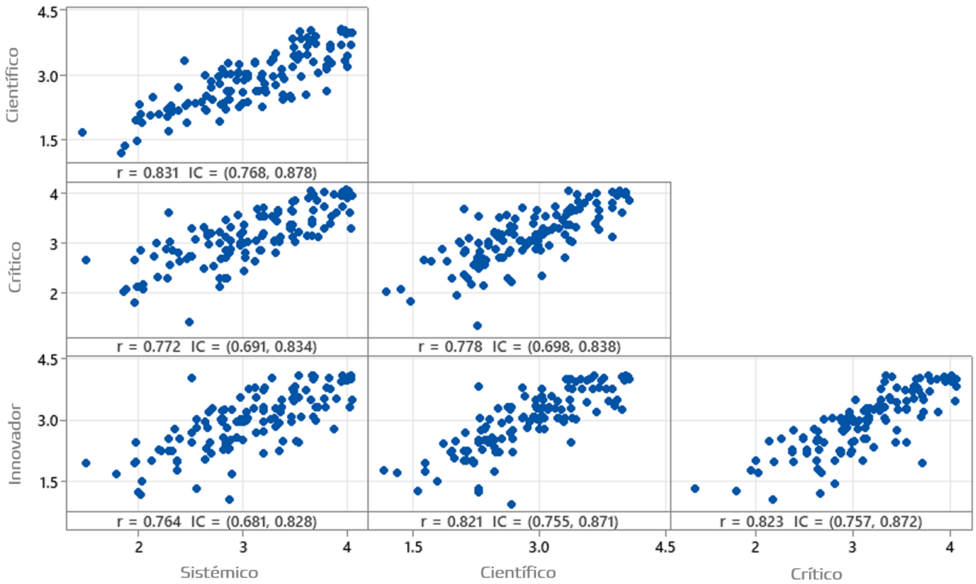
** The correlation is significant at the 0.01 level (two-tailed), n = 127.

Figure 2 shows the correlation coefficients with 95% confidence intervals. Systemic and scientific thinking exhibit a high correlation (r = .831), indicating that skills in one area are closely linked to those in the other. Similarly, systemic and creative thinking, as well as systemic and innovative thinking, exhibit strong correlations (r = .772 and r = .764, respectively), indicating a significant association between these types of thinking.

The correlations between scientific thinking and creative and innovative thinking are also strong (r = .778 and r = .821, respectively). The strongest correlation is between creative and innovative thinking (r = .823), reflecting a very close association between the ability to generate new ideas and the ability to apply them practically. The absence of p-values for the confidence intervals reaffirms the statistical significance of all the observed correlations.

Figure 2

Matrix Plots for Pearson Correlation



Whether the sample distribution complied with the parameters of normalcy was checked. Table 5 shows no extreme values for asymmetry (greater than |2.00|) or kurtosis (between 8.00 and 20.00) (Béjar, 1952; Borroni & De Capitani, 2022). It can be inferred that the sample follows a normal distribution. The standard deviations are relatively low in both the pre-test and the post-test; however, in the post-test, they decrease for each type of thinking, suggesting that the workshop may have contributed to greater homogeneity in the participants' responses.

The asymmetry in the pretest is slightly negative; in the posttest, it remains negative and becomes more pronounced in critical and innovative thinking, with a value of 0.43 in both. The asymmetries close to zero suggest a symmetrical distribution, but the presence of negative asymmetry in both tests indicates a general trend of the scores towards the upper end of the scale. The kurtosis in the pre-test varies, but it was close to zero or slightly negative for most self-assessments. In the post-test, kurtosis in systemic thinking became more negative (–0.61), while critical thinking showed a positive kurtosis (0.10) in the post-test, indicating a leptocurtic distribution.

After verifying the normality of the sample, we compared the total initial and final scores, as well as the scores by dimension. To do this, various statistical tests were used: 1) the comparison of outliers to identify if some values deviated significantly from the others in the sample data, 2) the Student's t-test, to compare the means of two independent groups and determine if there were statistically significant differences between them, 3) the paired t-test, to compare the means between the tests, and 4) the ANOVA test to analyze the differences between the two test scores to determine if the variations between the pretest and the post-test were greater than would be expected by chance.

Table 5

Descriptive analysis of the pre-test and post-test

	Pretest				Post-test			
	Mean	**SD**	**Asymmetry**	**Kurtosis**	**Mean**	**SD**	**Asymmetry**	**Kurtosis**
Systemic	2.9536	.6495	–.33	–.10	3.0879	.5994	–.29	–.61
Scientific	2.6890	.7049	–.11	–.62	2.8898	.6514	–.10	–.53
Critical	2.9088	.6333	–.28	–.22	3.1457	.5480	–.43	.10
Innovative	2.6969	.7558	–.03	–.62	2.9843	.7284	–.43	–.36

4. Analysis and results

The measurement of the difference in the means was carried out to discover atypical data. Figure 3 shows that the results in both tests fall within a similar range. However, they are slightly higher in the post-test in some dimensions, which could indicate a positive effect of the workshop. The increase in systems thinking was 0.130, which suggests a moderate improvement in self-assessment. Scientific thinking improved by 0.203, indicating that participants perceived themselves as having acquired an enhanced ability to analyze trends related to scientific entrepreneurship.

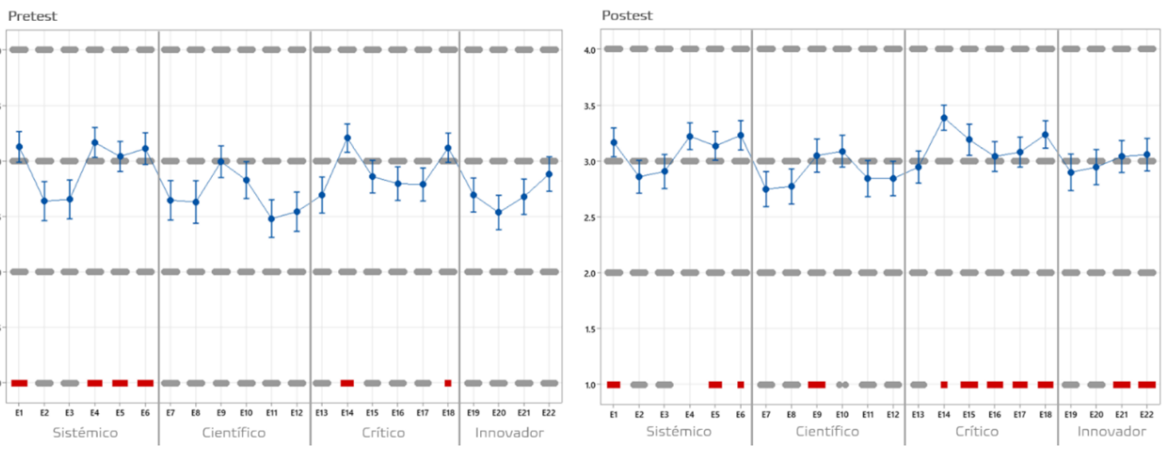
Critical thinking increased by 0.236, representing a significant improvement in participants' self-assessment of their ability to work with agile and lean design methodologies. In innovative thinking, the largest coefficient difference was 0.287, indicating progress in applying creative ideas in a practical and effective manner.

In Figure 3, the outliers (marked in red) are distributed throughout both tests, indicating significantly lower scores. This suggests that those participants may have had difficulty understanding concepts related to scientific entrepreneurship. There are no unusually high scores that could represent areas of strength. A review of the database revealed no answers that could pose a risk to continuing with the analysis.

To determine whether there were significant differences between the pretest and posttest, a Student's t-test was applied to the two samples. The results are presented in Table 6, showing a moderately strong Pearson correlation of 0.8329, indicating a positive correlation between the scores before and after the workshop; that is, participants who initially reported a high self-rating tended to maintain this rating. At the same time, those with lower assessment scores also showed a similar trend in the post-test (Lugo-Armenta and Pino-Fan, 2022).

Figure 3

Comparison of means between pre-test and post-test



Tukey's coefficient (Tα = 0.21) was used to evaluate the magnitude of the differences, yielding a sample difference of 0.02. This value indicates that the variations observed between the two measurements were minimal and did not exceed the threshold necessary to be considered statistically significant. Although the mean of the pretest was lower than that of the posttest, suggesting an improvement in the participants' self-ratings, the overall difference of 0.214, with a significance level of $p = 0.05$, indicates that this increase may be due to chance rather than an actual effect of the workshop. That is, although participants perceived a positive impact on their entrepreneurial skills, statistical analysis does not provide sufficient evidence to confirm that this improvement was conclusively attributable to the intervention.

Table 6

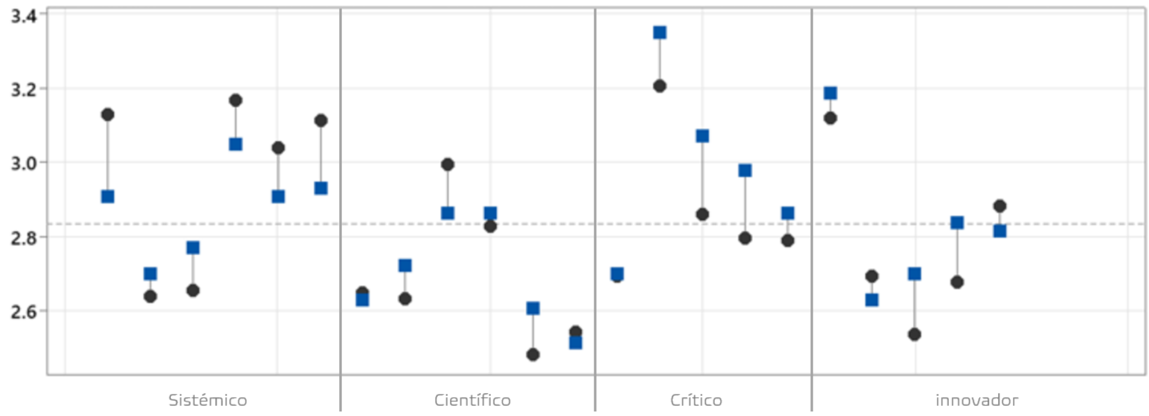
T-Test Statistics

	Pretest	*Post-test*	*Sample difference (sd)*	*Tukey's Method Tα=0.22*
Average	2.822409091	2.843551797	.02	Si Tα<sd=Non-significant difference
Variance	.051027396	.04023703		
Standard deviation	0.88318	.8042		
Pearson correlation	.832872721			

Figure 4 illustrates the paired data, indicating that the test reveals a significant difference between the mean of the post-test (3.0744) and the mean of the pre-test (2.1274), with a difference of 0.9470 ($p < 0.001$). This result, with a 95% confidence interval and a lower standard deviation in the paired differences, confirms that the workshop had a statistically positive effect on the students' self-assessment. The variability of the standard deviation in the post-test, although increased, did not compromise the overall effectiveness of the workshop.

Figure 4

Paired t-test between pretest and post-test



An ANOVA analysis using a fixed-effect factor was conducted to determine whether the observed differences between the pretest and posttest were statistically significant. The results, presented in Table 7, demonstrate a significant impact of the workshop on the students' self-assessment of their competency in complex thinking. In particular, the calculated F coefficient of 129.095 was higher than the critical one (Fc = 4.06170), indicating that the variations between the measurements were not attributable to chance. Likewise, the p-value obtained (1.35405E-33) refuted the null hypothesis that there were no significant changes in the participants' self-assessment.

These findings suggest that the intervention positively impacted the students' perception of their entrepreneurial skills, strengthening their complex thinking. Although the Student's t-test showed no significant differences in overall means, the ANOVA analysis confirmed that the observed variability between pre- and post-workshop measurements was sufficiently high to suggest that the program influenced participants' self-assessments. This reinforces the importance of implementing training strategies that promote complex thinking in scientific entrepreneurship while also highlighting the need for complementary studies that delve deeper into the causal relationship between intervention and the development of these competencies (Sisso et al., 2023).

Table 7

Simple factor (One-way) ANOVA

Summary

Groups	*Count*	*Sum*	*Average*	*Variance*
Pre	23	48.9296	2.127373913	.0405712
Post	23	14.8006	.643504348	.0015239

ANOVA

Source of variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between groups	25.3214922	1	25.3214922	1203.0607	1.35405E-33	4.0617
Within the groups	0.926092634	44	.02104756			
Total	26.24758483	45				

In general, the results indicate an improvement in the participants‘ perception of entrepreneurial skills between the pre-test and the post-test, supported by an increase in the means of the dimensions evaluated. Innovative thinking showed the highest increase, with a difference of 0.287 points, followed by critical thinking, which increased by 0.236 points. Although these differences were not statistically significant, they reflect a positive trend in the participants‘ self-assessment, which suggests a favorable effect of the workshop on the development of entrepreneurial skills. Additionally, the perception of improvement may reflect a subjective progress in self-assessment, which is relevant to the participants‘ motivation and willingness to undertake ventures.

These results may be related to the practical nature of the workshop, which enabled students to apply their knowledge in creating projects based on real-life situations, thereby strengthening their innovation and critical thinking skills. Additionally, collaborative interactions during the identification, ideation, invention, and information stages could have enhanced their entrepreneurial capabilities.

5. Discussion

In this study, improvements in students‘ entrepreneurial skills were evaluated with a quantitative pretest-posttest approach. One of the findings shows that their self-assessment of scientific entrepreneurship skills improved significantly between the two tests. Figure 3 shows an increase in the systems thinking mean from 2.9536 to 3.0879, suggesting a moderate improvement. According to Piñeiro-Chousa et al. (2020), the development of entrepreneurial skills is crucial for vocational training. This result underscores the importance of incorporating educational programs that focus on entrepreneurial skills, highlighting the positive impact of the workshop on students.

Additionally, critical thinking skills demonstrated a noticeable increase in participants' self-worth. Critical thinking increased by 0.236, indicating a significant development in the ability to work with agile and lean design methodologies. Fernández et al. (2022) state that entrepreneurial competencies are related to skills that can be acquired through education and training. In this sense, the improvement in critical thinking also suggests that the workshop provided effective tools for developing essential critical skills in scientific entrepreneurship.

In our study, the innovative thinking dimension had the largest increase between the two tests, indicating significant progress. The increase of 0.287 indicated an advancement in the practical application of creative ideas, confirming that the ability for entrepreneurship arises from the integral interactions of the students with their socialization environment (Duval-Couetil et al., 2021). This increase in innovative thinking reflects students' ability to generate creative solutions, evidencing the value of an educational approach that develops complex thinking.

On the other hand, the positive correlation between the pre-test and post-test scores was not statistically significant. Pearson's correlation coefficient was 0.8329, and the difference measured by Student's t-test was 0.02, which did not reach statistical significance. Although the correlation was not statistically significant, it suggests a positive trend in self-assessment of competencies, highlighting the importance of educational programs focused on entrepreneurship. This finding reinforces the need to consider the demands of the current work environment in academic training (Boyle et al., 2021).

However, the ANOVA test results confirmed a significant effect of the workshop on the students' self-assessment. The F coefficient was 129.095, substantially higher than the critical Fc value of 4.06170. The p-value was practically zero (1.35405 × 10^33). This finding supports the effectiveness of the workshop in improving complex thinking competencies, aligning with the need to integrate digital skills in higher education.

The nature of each statistical analysis can explain differences in results between the two tests. The t-test exclusively compares the means of the pretest and posttest, which may make the test less sensitive to variations within the group if the sample is small or if there is high individual variability in the scores. In contrast, ANOVA assesses total variability and allows us to identify more subtle effects when considering differences between and within groups, which increases its ability to detect significant changes. In addition, the impact of the workshop may not be reflected uniformly among all participants, which could dilute the significance in the pre-test/post-test analysis but become more evident in ANOVA's assessment of variability. Factors such as the duration of the workshop, the initial level of students' competencies, and their predisposition to self-evaluation may have influenced these results.

However, it is worth noting that the results indicate a greater homogeneity in the participants' responses following the workshop. The standard deviation decreased in the post-test for each type of thinking, suggesting greater uniformity in self-assessments. In this regard, Macías et al. (2020) note that complex thinking necessitates a systemic and critical approach grounded in current educational realities. Thus, the reduction in the variability of the responses indicates that the workshop contributed to a more uniform and consolidated understanding of the competencies, highlighting its effectiveness.

Similarly, participants perceived their scientific entrepreneurship skills more positively after participating in the workshop. Scientific thinking improved by 0.203, indicating an enhanced ability to analyze trends related to scientific entrepreneurship. This suggests that students can develop scientific entrepreneurial skills, highlighting the potential of educational interventions to foster entrepreneurship (Farida et al., 2022). Another finding shows that the perception of skills in systems thinking also improved. The average score for systems thinking increased from 2.9536 in the pre-test to 3.0879 in the post-test. This highlights that the improvement in systems thinking reflects a better ability to integrate scientific knowledge into entrepreneurial projects. Therefore, this study's findings suggest that the development of complex thinking through the workshop influenced the participants' self-assessment of their entrepreneurial skills. However, it is essential to analyze how these improvements can be applied in real-world scientific entrepreneurship. The practical application of these competencies is reflected in students' ability to identify opportunities in their areas of expertise, design innovative solutions, and communicate their ideas effectively. So, methodologies such as challenge-based learning, the use of digital tools for project ideation, and the application of rapid prototyping models were key to promoting critical thinking and fostering innovation. These strategies enabled participants to develop structured approaches to solving complex problems and, simultaneously, acquire an entrepreneurial mindset aligned with the realities of the scientific and technological sectors.

The results underscore the importance of educational programs that develop complex thinking for scientific entrepreneurship. Improvements in the self-assessment of entrepreneurial skills demonstrate the positive impact of the workshop. These findings suggest that training experiences focused on higher skills can enhance scientific entrepreneurship, contributing to the development of innovative and sustainable solutions.

5. Conclusions

Complex thinking is an essential catalyst in scientific entrepreneurship, enabling innovators to unravel and address the intricate webs of contemporary problems with creative and sustainable solutions. This study aimed to analyze the self-assessment of complex thinking in the development of scientific entrepreneurship skills among students at the Universidad San Carlos de Guatemala, utilizing a workshop on scientific entrepreneurship with a future-oriented vision. The findings show (a) an improvement in the perception of students' entrepreneurial skills after completing the workshop, which reflects the potential effectiveness of the educational program, although these improvements did not reach statistical significance, and, (b) the development of scientific entrepreneurship is facilitated through cultivating advanced competencies, such as complex thinking, and that using well-designed educational experiences, together with learning platforms, can increase their self-assessment of entrepreneurial skills.

For educational practice, these results underscore the importance of integrating didactic strategies that promote complex thinking and entrepreneurial self-awareness, utilizing digital resources and formative assessments that motivate students to apply and reflect on their skills in real-world contexts. Regarding research implications, this study encourages the adoption of diversified analysis methods, considering broader and more varied populations (including different student profiles, disciplines, types of universities, and countries) and exploring different educational contexts to deepen the understanding of how specific pedagogical interventions impact the development of scientific entrepreneurship.

Although the results suggest an improvement in the self-assessment of scientific entrepreneurship skills following participation in the workshop, it is essential to note that these differences were not statistically significant. This implies that, although participants perceived a positive impact on their development of entrepreneurial skills, these changes may have been influenced by subjective factors or factors external to the program. Therefore, it is recommended that the findings be interpreted with caution and that additional studies with more robust experimental designs and larger sample sizes be conducted to obtain a more accurate assessment of a workshop's impact.

A significant study limitation is the sample's size and composition, as it focuses on a single educational institution. This may lead to findings being influenced by specific contextual factors, such as the students‘ academic profile, the institutional culture, and the available resources. This makes it challenging to generalize the results to other populations with different characteristics.

Likewise, the intervention’s short duration may not have been long enough to generate a profound and sustained impact on the development of entrepreneurial skills. Some effects of the workshop may only become apparent in the medium or long term, which would not be captured in this evaluation. Additionally, students' self-assessment, used as the primary measure of assessment, may be subject to perceptual biases and may not accurately reflect actual changes in their abilities. Another aspect to consider is that the study did not account for external variables that could have influenced the results, such as students' prior experiences in entrepreneurship, their level of motivation, or the potential impact of other courses or concurrent activities.

However, despite these limitations, this study can serve as a starting point for the development of new lines of research on the impact of educational interventions on scientific entrepreneurship. Future studies could expand the scope by exploring the effectiveness of similar programs in different types of enterprises and institutions. Additionally, it would be beneficial to utilize a broader range of assessment instruments, including both qualitative and quantitative measures, to gain a more comprehensive understanding of the development of entrepreneurial skills. Likewise, an expansion of the population studied would enable a more in-depth analysis of the dynamics of scientific entrepreneurship in various educational settings, thereby contributing to the development of more robust and generalizable strategies for its promotion in higher education.

Author contributions

Conceptualization, C.E.G.R.; data curation, C.E.G.R.; CEGR, and LMOC; acquisition of financing, C.E.G.R.; research, C.E.G.R. and L.M.O.C.; methodology, C.E.G.R.; project management, C.E.G.R. and L.M.O.C.; resources, C.E.G.R.; C.E.G.R. and L.M.O.C.; supervision, C.E.G.R.; validation, C.E.G.R.; visualization, L.M.O.C.; writing—preparing the original draft, CEGR; writing—proofreading and editing, C.E.G.R. and L.M.O.C.

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Data Availability Statement

The data set used in this study is available at reasonable request to the corresponding author

Ethics approval

Not aplicable

Consent for publication

The author has consented to the publication of the results obtained by means of the corresponding consent forms.

Conflicts of interest

The author declares that they have no conflict of interest

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