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University of Almeria, Spain

*CORRESPONDENCE
Marco Cruz-Sandoval
✉ cruzsandovalmarco@tec.mx

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Complex thinking and adopting artificial intelligence tools: a study of university students

José Carlos Vázquez-Parra[1], Carina Soledad Gonzalez-Gonzalez[2], Juan Alberto Amézquita-Zamora[3], Andrea E. Cotino Arbelo[2], Sergio Palomino-Gámez[4] and Marco Cruz-Sandoval[4]*

[1]Institute for the Future of Education, Tecnologico de Monterrey, Guadalajara, Mexico, [2]School of Engineering and Technology, University of La Laguna, San Cristóbal de La Laguna, Spain, [3]School of Humanities and Education, Tecnologico de Monterrey, Guadalajara, Mexico, [4]Department of Sustainable Technologies and Civil Engineering, School of Engineering and Sciences, Tecnologico de Monterrey, Mexico City, Mexico

In the next 5 years, artificial intelligence (AI) tools are expected to become commonplace in people's lives, especially in their work processes. Therefore, educational institutions feel intrinsically responsible for ensuring that their students acquire and develop competences associated with the appropriate use of this technology in their educational programs. However, what are the perceptions of students regarding the inclusion of artificial intelligence tools in their educational process and future careers, and what competencies can influence a greater adoption of this technology in the classroom? The objective of this article presents the results of an exploratory study in a sample population of students from a technological university in Mexico, in which their perception and openness toward the training and use of artificial intelligence tools for their professions was examined. Their perception of the development of complex thinking and its sub-competencies was evaluated, recognizing that complex thinking is a valuable cognitive skill to face changes in uncertain environments. The methodology of the study consisted of a multivariate descriptive statistical analysis using R software. The results determined a positive correlation between students' perceived improvement in the achievement of complex thinking competence and their perception of the use of AI tools. In conclusion, participants perceived the use of these tools as a feature of their profession, although they questioned whether this knowledge is included in their professional training. This article presents several findings that offer ample opportunities for future research.

KEYWORDS

professional education, educational innovation, life-long learning, complex thinking, artificial intelligence, higher education

1 Introduction

Undoubtedly, AI tools are no longer exclusive to particular disciplines or specialized tasks because today, it is feasible to find this type of technology in practically all professions (Baker, 2023). According to "The Future of Jobs 2023" report of the World Economic Forum (2023), the inclusion of tools with artificial intelligence is a necessary evolution for many professions and industrial tasks because repetitive or automatable activities are easily performed by this technology, forcing individuals to migrate to activities that involve higher cognitive skills (Alkaissi and McFarlane, 2023).

Along the same lines, universities increasingly include in their curricula the acquisition and development of skills associated with the use of artificial intelligence, which implies not only a continuous technological adoption but also the questioning of established paradigms about the meaning of professional work (Amézquita Zamora, 2023). As with any educational innovation, artificial intelligence tools challenge teachers and students, who must adapt to a continuously changing reality, acquire more flexible knowledge, and develop competencies that will enable them to face the challenges of their future professions (Bian et al., 2023). Thus, the incursion of artificial intelligence tools in the educational field implies considering their classroom training and the development of competencies and associated skills that allow their adequate, sustainable, and integrated use (Lo, 2023).

Promoting students' openness to these tools is relevant because it is not enough to acquire knowledge about using them; they must be adopted in the new job profiles of their future professions (Memarian and Doleck, 2023). In this sense, the acquisition and development of cognitive skills that include flexible vision and openness to change are very relevant, as is the case of the complex thinking competency, which promotes an integrated vision of the environments and challenges of an uncertain world (Amézquita Zamora, 2023).

In this sense, what are the perceptions of students regarding the inclusion of artificial intelligence tools in their educational process and future careers, and what competencies can influence a greater adoption of this technology in the classroom?

This article presents the results of an exploratory study conducted on a sample population of students from a technological university in Mexico who were asked about their perception and openness to the training and use of artificial intelligence tools for their professions. Complementarily, the study assessed their perceived achievement of complex thinking and its sub-competencies, considering that this is a valuable cognitive ability to face environmental changes. The objective was to evaluate their perception of the teaching and incursion of this new technology in professional training and assess whether it correlated with specific cognitive skills such as critical, systemic, scientific, or innovative thinking. The methodology involved multivariate descriptive statistical analysis using R software.

The hypothesis motivating this study is that students' perceptions of and openness to the inclusion of artificial intelligence tools in their educational process and future careers are positively correlated with their competencies in complex thinking and its sub-competencies, such as critical, systems, scientific and innovative thinking. Higher levels of these cognitive competences will lead to greater adoption and more effective use of artificial intelligence technology in both their educational process and professional performance.

This study is relevant because it examines the inclusion of artificial intelligence tools in education, not just as software but as an evolution in professional processes. It analyzes the relationship between the adoption of these technologies by students and their cognitive skills, such as complex thinking, offering practical implications for educational institutions. Additionally, it supports research on complex thinking and highlights the need to prepare students with the necessary skills for effective adoption of artificial intelligence.

In terms of its structure, this article will first approach the subject of the use of AI in education, considering different academic approaches and studies previously carried out, as well as a reflection on how these tools can be associated with the development of competences and skills. Then, the methodology used for this study will be presented, as well as the results of this research. The discussion contrasts the findings with other research, closing with a conclusion that includes the theoretical and practical implications of the results.

2 Theoretical framework

2.1 Relevance of training and inclusion of artificial intelligence tools in universities' educational processes

We must imagine a world where machines perform tasks and can learn, connect, and adapt (Huang and Rust, 2020) in a reality beyond our present perspective. The current landscape of reality, in which various AI tools play essential roles in everyday life, sometimes with the autonomy to make decisions that directly affect people, is a present just beginning to be understood (Borenstein and Howard, 2021). Simultaneously, the complexities of coexistence between humans and algorithms come to light; these redefine people's everyday interactions and the boundaries of what was not long ago considered possible (Losbichler and Lehner, 2020). The division between people and machines disappears in this combination of algorithms and automatic decisions. With every correct prediction and every lesson learned, AI-enabled tools continuously evolve in their value as companions, adapting to users' interests (Huang and Rust, 2020).

Artificial intelligence transcends conventional knowledge barriers and manifests as a force spanning all domains. Mastering these tools in the professional domain is essential (Jensen et al., 2020), underscoring the need to incorporate these tools into universities' educational training. Future professionals should be able to understand and apply these technologies to foster innovation and adaptability in their future careers and enrich their education (Zhai et al., 2021). Integrating tools with artificial intelligence is a step toward modernizing higher education and investing in students' preparation for the challenges and opportunities of Industry 4.0, which is characterized by the integration of digital technologies, the Internet of Things (IoT), cloud computing, advanced robotics, and data analytics (Auon et al., 2021).

UNESCO has already published a report analyzing curricula with existing AI-enabled tools, explicitly focusing on curricular content and expected learning outcomes in early childhood, primary, and secondary education, addressing the concept of artificial intelligence as a specific competency (United Nations Educational, Scientific and Cultural Organization, 2023). Its commitment to ensuring the quality of education underscores the importance of effectively integrating artificial intelligence at all educational levels, as the value of applying these tools in education is potent, impacting both students and educators. This technology provides students with the skills necessary to function in a workforce using these tools while empowering educators to adopt dynamic and personalized pedagogical approaches (Chen et al., 2020; Zawacki-Richter et al., 2019).

In particular, the advent of ChatGPT and other tools with generative artificial intelligence has sparked intriguing debates in various fields, especially in education. These discussions focus on maximizing the opportunities and mitigating the risks associated with these disruptive technologies. With tools such as ChatGPT freely and easily accessible, we reach the cusp of a new era in technological development, which calls for re-evaluating learning and teaching methods to meet the challenges of the modern world (González-González, 2023). The advantages of their use in the classroom, including facilitating autonomous learning or personalized learning, must be weighed against the challenges and ethical considerations regarding the reliability and accuracy of their results, privacy, ethical management of information, and the excessive technological dependence on these tools that can negatively affect the development of independent research and critical thinking skills (González-González, 2023). Ultimately, the success of integrating tools such as ChatGPT into education will depend on how educators and students use them critically, ethically, and effectively.

So, regardless of academic discipline, the integration and training of artificial intelligence tools provide students and teachers with skills in emerging technologies to meet the challenges of the 21st century. The training and implementation of these technologies are no longer optional but necessary in today's educational and professional landscape. Rapid technological evolution demands professionals and citizens capable of understanding, adapting, and leading in a highly competitive digital environment (Howard, 2019). Moreover, it is essential to cultivate, from the foundational stages of their use, an ethical and reflective understanding of the application of these tools to ensure good practices (Morley et al., 2020; Zawacki-Richter et al., 2019). In doing so, universities play a crucial role in training a generation of professionals prepared to understand the workings of an increasingly interconnected society driven by artificial intelligence.

2.2 Interdisciplinary perspectives on AI in education

The use of tools with artificial intelligence (AI) in university education is revolutionizing the way we learn and teach. Thanks to cognitive psychology, we know that each student has their own pace and style of learning. This is where AI excels, as it can individually adapt to offer a personalized and effective educational experience. By adjusting to each student's unique learning patterns, AI tools not only facilitate the understanding of content but also enhance information retention (Taylor and Taylor, 2021). The use of these technological tools is also crucial in developing key skills such as critical thinking and the ability to solve complex problems. AI platforms that provide immediate and personalized feedback strengthen students' ability to regulate their own learning, better preparing them for the real-world challenges they will face in their careers (Zhao et al., 2022).

However, the use of AI in education also raises important questions from the perspective of the philosophy of technology. It is crucial to consider how these tools affect students' autonomy and reflect on the technological dependency they might create. We must ensure that the use of AI is fair and does not invade privacy or perpetuate existing biases, ensuring that the benefits of these technologies are accessible to everyone (Boddington, 2023).

In teaching STEM disciplines (science, technology, engineering, and mathematics), AI presents itself as a powerful tool to innovate and enrich teaching methods. By analyzing large volumes of data and simulating complex scenarios, AI enables the creation of more interactive and practical learning experiences, which not only improves technical understanding but also empowers students to use technology in creative and critical ways. The challenge lies in finding the right balance between adopting new technologies and maintaining the human interactions that are fundamental in education (Llorca Albareda, 2024). Looking to the future, universities should aspire to integrate AI in such a way that it complements and enriches existing teaching methodologies, without replacing the valuable human contact that enriches the educational process (Mainzer, 1990). This will prepare students not only to face the future with advanced skills but also to use technology ethically and consciously in an increasingly digital world.

2.3 Competency-based education and complex thinking

To begin with, we must characterize what complex thinking means and what it means for it to be a competency. We start from the competencies proposed by Tobón (2013): they "are an integral performance, they seek to solve problems, focus on continuous improvement and are based on ethical performance" (p. 119). Such characterization embraces an idea of education where memorizing content is not essential but instead adequately mastering the rudiments of a field of knowledge to modify and transform it contextually according to the problems faced, flexibly and timely, leveraging all a person's potential, including responsibility. It means having the capacity for deliberate action guided by the obligations one has to the role one plays in society, the aptitude for accountability for the consequences of such action, the commitment to the public good (Amézquita Zamora, 2021), and the ability to learn from one's mistakes and continuously optimize executed actions. Thus, competency-based education covers the conceptual contents of knowledge and its affective-motivational or attitudinal dimension (attitudes and values). It links with the dimension of "doing" (procedural and technical skills) so that the comprehensive performance of the competencies has a dynamic relationship with knowing how to know, how to be, and how to do (Tobón, 2013; Vázquez Parra et al., 2023).

It is also essential to remember that competency-based education intends to solve problems, which implies research training (Tobón et al., 2012). It is necessary to know how to research to adequately identify the problem to be solved, collect relevant information (data, evidence, background), evaluate it critically, generate creative solutions, validate the approaches and approaches that generated such solutions, decide in an informed manner, and adapt flexibly as the information about the problem changes or new important information is obtained (Guisasola Aranzábal et al., 2011). On the other hand, as presented so far, problem-solving has a determining characteristic: appropriateness. That is, it is not about solving problems in any way or only with criteria of promptness and quantity but also with criteria referring to quality, adequate use of resources, timeliness of the intervention, and attention to the context (Tobón, 2013), all of which "requires very good conceptual, methodological and attitudinal training" (Tobón et al., 2012, p. 102). Each of these elements alone does not constitute a competency, but all are involved simultaneously in its comprehensive performance.

Given the above, it is understandable why those who promote competency-based education argue that there is a necessary link between the understanding provided by complex thinking and the proposal of education by competencies because only people who have adequately developed the competencies that higher education seeks to train will be able to take on the challenges of a complex world.

Considering the previous approaches, Tecnologico de Monterrey transformed its educational model (Tec21 Educational Model), adopting complex thinking as a transversal competency to be developed by its students throughout their professional preparation, calling it "reasoning for complexity" and characterizing its development as follows:

> "The aim is to train a professional capable of applying integrative thinking that enables the analysis, synthesis, and solution of problems and continuous learning through the mastery of the cognitive skills necessary to use scientific, critical, and systemic thinking according to the challenges that their current and future context will demand in the exercise of their profession and in the commitment as a citizen with the transformation of the environment" (Tapia Gardner, 2019).

This conception of reasoning for complexity included three sub-competencies that integrate it: scientific, systemic, and critical thinking (Tapia Gardner, 2019). To these three sub-competencies, the Reasoning for Complexity research team of the Institute for the Future of Education at Tecnologico de Monterrey added the sub-competency of creative or innovative thinking (Castillo Martínez et al., 2023; Vázquez Parra et al., 2023; Cruz Sandoval et al., 2023), which is also considered a sub-competency of complex thinking by other researchers (Silva Pacheco and Iturra Herera, 2021; Tobón and Luna Nemecio, 2021). For this research, based on Tapia Gardner (2019) and Tecnologico de Monterrey (2020), we propose a particular view of the competency of reasoning-for-complexity and its sub-competencies per the formulations Tobón (2013) proposes (see Table 1).

These notions reveal that complex thinking encompasses relevant cognitive skills to face the uncertainty of a changing world and adopt new technologies, such as this case with artificial intelligence tools. The motivation of this study was to determine if there is a possible relationship between the development of complex thinking and university students' perceptions of the use and adoption of these technologies in their professions.

3 Methodology

3.1 Population and design

This article describes an exploratory study conducted on a sample of 53 students attending a technological university in Mexico. It assessed their perception and attitude toward the training with artificial intelligence tools for their profession and their perceived achievement of complex thinking and its sub-competencies. The sample comprised students in different semesters of six disciplines: Engineering, Humanities and Education, Social Sciences, Health Sciences, Business and Architecture, and Art and Design. This sample had 20 men and 33 women, intending a similar proportion to the overall enrollment of the institution.

The implementation occurred during the academic semester of August–December 2023, using a digital Google Forms instrument. Following ethical research principles, the study adhered to ethical institutional parameters, so all participants consented to be included in the sample and allowed their responses to be used for academic and research purposes. The university's R4C Research Group regulated the study with technical support from the Writing Lab at the Institute for the Future of Education at Tecnologico de Monterrey.

3.2 Instrument

This study applied two validated instruments:

1 Attitudes and perceptions of students toward artificial intelligence: This instrument was designed by Sit et al. (2020)

TABLE 1 Formulation of the reasoning for complexity competency and its sub-competencies.

Competency: Reasoning for complexity. Articulates different cognitive skills to identify, pose, and solve personal, professional, or social challenges and problems integrally and responsibly, considering contextual challenges and the disposition toward continuous learning.
Sub-competencies I. Systemic thinking: Approaches problems from different perspectives to understand them holistically, combining, interconnecting, and contextualizing knowledge from different sources and disciplinary areas to propose efficient solutions.
II. Scientific thinking: Proposes solutions to problems and questions reality by applying valid and reliable methodologies for collecting, analyzing, synthesizing, and evaluating information with an interdisciplinary perspective, rigor, and academic integrity.
III. Critical thinking: Evaluates with respect and empathy the soundness of arguments, whether their own or those of others, identifying fallacies and contradictions to form judgment and take a position on a problem or challenge.
IV. Creative/innovative thinking: Approaches problems and challenges from diverse perspectives, even those that contradict their points of view, to generate solutions that did not previously exist.

Own elaboration based on Tobón (2013), Tapia Gardner (2019), and Tecnologico de Monterrey (2020).

to measure students' attitudes and perceptions regarding the teaching and use of artificial intelligence tools in their professional training. It was validated during its employment among King's College London medical students. The questionnaire instrument consisted of 11 items answered on a 5-point Likert scale, in which participants rated their agreement with a statement about their current attitudes toward artificial intelligence, their professional intentions to use it, their current understanding of these tools, their openness to its adoption in their professional curricula, and their confidence in using artificial intelligence tools routinely and critically. In addition, a dichotomous question determined whether participants had received training in artificial intelligence and whether this training was mandatory in their curriculum. Although the original instrument was for medical students, it is possible to find derivations to other areas of knowledge, such as the one by Almaraz-Menéndez and López-Esteban (2023), who applied it to Business and Education students at the University of Salamanca.

As part of the process of validating the instrument and adapting it for a Latino population across disciplines, a validation was carried out using GSEM estimation with Quasi-maximum likelihood (QML), using data collected from 238 university students from an educational institution in Mexico. The results indicated that (i) the items of the instrument helped to explain the attitude and perception of students on the importance of receiving adequate training in the use of these tools, and (ii) the contrast metrics confirmed the quality of the model fit. Considering this validation, the present study applied this instrument to all disciplines.

Some of the items included in this instrument are:

1 AI will play an important role in the teaching and development of my profession.
2 Some job profiles related to my profession will be replaced by AI during my lifetime.
3 I understand the basic principles of AI - how it works and how it is used.
4 I am comfortable with the terminology related to AI and can discuss the topic with my colleagues and acquaintances.
5 I understand the limitations of AI in my discipline or profession.
6 I comprehend the ethical implications of using AI in my discipline or profession.
7 Training in AI will be beneficial for my professional career.
8 All students and professionals in my discipline should receive training in AI.
9 Having training in AI would give me the confidence to use basic AI tools if necessary.
10 Having training in AI would allow me to basically evaluate the different tools and AI algorithms existing in the discipline or profession.
11 In general, having training in AI would provide me with the basic knowledge needed to routinely work with AI in my discipline or profession.
12 Have you received any type of training—class, course, workshop—on the use of AI in your profession?

2 E-Complexity: E-Complexity is a Likert-type questionnaire designed to assess students' perception of their mastery of complex thinking competency and its sub-competencies (Castillo Martínez et al., 2023). It consists of 25 statements rated on a 5-level Likert scale, from "Strongly disagree" (1) to "Strongly agree" (5) (Castillo Martínez et al., 2023). This instrument underwent a three-stage validation process: theoretical, design, and content validation by experts. The theoretical validation analyzed other similar instruments, revealing the need for a comprehensive instrument. The design of E-Complexity conceived complex reasoning competency and its sub-competencies (Castillo Martínez et al., 2023).

Content validation with experts examined three criteria: clarity, coherence, and relevance (Escobar-Pérez and Cuervo-Martínez, 2008). The experts rated the items according to these criteria, obtaining high scores on all three, with scores above 60%, indicating high validity (scores between 3 and 4). In addition, the correlations between the experts' ratings for clarity, coherence, and relevance were low, suggesting independence among the criteria. The two-phase validation process was supplemented with Partial Least Squares Structural Equation Modeling (PLS-SEM) using data from 1,037 university students. The outcome of this third phase affirmed the validity and reliability of E-Complexity within a knowledge-based educational framework, particularly in measuring the perceived achievement of the complex thinking competency and its sub-competencies. The application of the Partial Least Squares Method (PLS-SEM), chosen due to the non-normal data nature, revealed that (i) 76.28% of the variability in latent variables was explained by observed variables and (ii) discriminant validity demonstrated low correlations between squared factors compared to the average variance extracted (AVE), signifying strong discriminant validity (Vázquez-Parra et al., 2024).

In a pilot study of 999 participants, the instrument demonstrated strong internal consistency, with a KMO index above 0.80, a p-value below 0.05, and a Cronbach's Alpha of 0.93. Confirmatory factor analysis validated the instrument, and further reliability tests using McDonald's Omega and Guttman's Lambda showed scores over 0.8 for each subcompetency, confirming the instrument's reliability and internal consistency.

Some of the items on this instrument are:

1 I have the ability to find associations among variables, conditions, and constraints in a project, challenge, or problem I face.
2 I identify data from my discipline and other areas that contribute to solving problems.
3 I participate in projects that need to be resolved using inter/multidisciplinary perspectives.
4 I organize information to solve problems.
5 I enjoy knowing different perspectives of a problem.
6 I lean toward strategies to understand the parts and the whole of a problem.
7 I have the ability to identify the essential components of a problem to formulate a research question or hypothesis for its solution.
8 I am familiar with the structure and formats for preparing research reports used in my area or discipline.

TABLE 2 Complex thinking: mean and standard deviation values.

	Men		Women		Total	
	Mean	SD	Mean	SD	Mean	SD
Systemic thinking	4.05	0.51	4.07	0.53	4.06	0.52
Scientific thinking	3.68	0.6	3.7	0.71	3.69	0.66
Critical thinking	3.88	0.48	4.09	0.49	4.01	0.49
Innovative thinking	3.85	0.58	3.97	0.53	3.93	0.54
Complex thinking	3.86	0.47	3.95	0.49	3.91	0.48

Total and by gender.

9 I identify the structure of a research text that is handled in my area or discipline.
10 I identify the elements to formulate a research question or hypothesis.
11 I design clear and coherent methodologies or processes to solve problems in my profession.
12 I formulate and test hypotheses when facing a problem or challenge.
13 I tend to use scientific data to analyze problems.
14 I have the ability to critically analyze problems from different perspectives.
15 I identify the foundation of my own and others' judgments to recognize false arguments.
16 I self-assess the level of progress and achievement of my goals to make necessary adjustments.
17 I use reasoning based on scientific or theoretical knowledge to make judgments in the face of a problem.
18 I ensure to review the ethical guidelines of the projects in which I participate.
19 I appreciate criticism in the development of projects to improve them.
20 I am aware of the criteria for determining a problem.
21 I have the ability to identify variables, from various disciplines, that can help answer questions.
22 I apply innovative solutions to various problems.
23 I solve problems by interpreting data from different disciplines.
24 I analyze problems considering the context to create solutions.
25 I tend to evaluate with critical and innovative sense the solutions derived from a problem.

3.3 Data analysis

The data analysis used a multivariate descriptive statistical approach with R software (R Core Team, 2017) and RStudio (RStudio Team, 2022). This analysis focused on calculating mean values and standard deviations to describe the distribution and variability of the data set. In addition, box plots helped to visualize the distribution. Subsequently, significance analyses used tests of difference of mean values through ANOVA and *t*-tests. These tests were performed with a 95% confidence interval, implying a *p*-value of 0.05. Finally, a scatter plot complemented by a linear regression line explored the possible relationship between the variables.

4 Results

Table 2 presents a detailed analysis of the mean values and standard deviation in students' self-perception of developing complex thinking competency and its sub-competencies. Regarding the overall complex thinking competency, students perceived themselves with a mean value of 3.91. Notably, students perceived themselves as more competent in systems thinking, with a mean value of 4.06, followed closely by critical thinking, with a mean of 4.01. In contrast, the sub-competencies of innovative and scientific thinking were perceived with less development, attaining mean values of 3.93 and 3.69, respectively.

Figure 1 complements the information presented in Table 2, illustrating the dispersion in students' self-perception of developing the sub-competencies of complex thinking, differentiated by gender. This visualization reveals that, in general, female students perceived themselves to have a higher level of development in all sub-competencies than their male peers. Specifically, female students self-assessed themselves with the highest development of critical thinking (4.09) and systemic thinking (4.07), while they attained lower means in scientific thinking (3.7) and innovative thinking (3.97). In contrast, male students perceived themselves as strongest in systems thinking (4.05) and least developed in scientific thinking (3.68). In addition, Figure 1 highlights that the variability in responses was higher among females, with a notable presence of outliers in the lowest quartile.

To explore the potential differences in how men and women perceive their development of complex thinking and related sub-competencies, we conducted a statistical *t*-test, the results of which are detailed in Table 3. Interestingly, the analysis indicated no statistically significant differences between genders in their self-assessment of these cognitive abilities. This finding suggests that both men and women view their development in complex thinking and its various aspects—such as analytical skills, problem-solving abilities, and critical evaluation—on equal terms. This outcome aligns with the growing body of research that challenges traditional stereotypes about gender-specific cognitive abilities, thereby supporting the notion that the capacity for complex thought does not vary significantly between men and women.

Figure 2 offers a detailed visual representation of the dispersion of mean values regarding the perceived development of complex thinking sub-competencies, categorized by academic discipline. The graph is particularly useful for observing how students from various fields perceive their abilities in areas such as analytical thinking, problem-solving, and critical reasoning. A striking feature of this

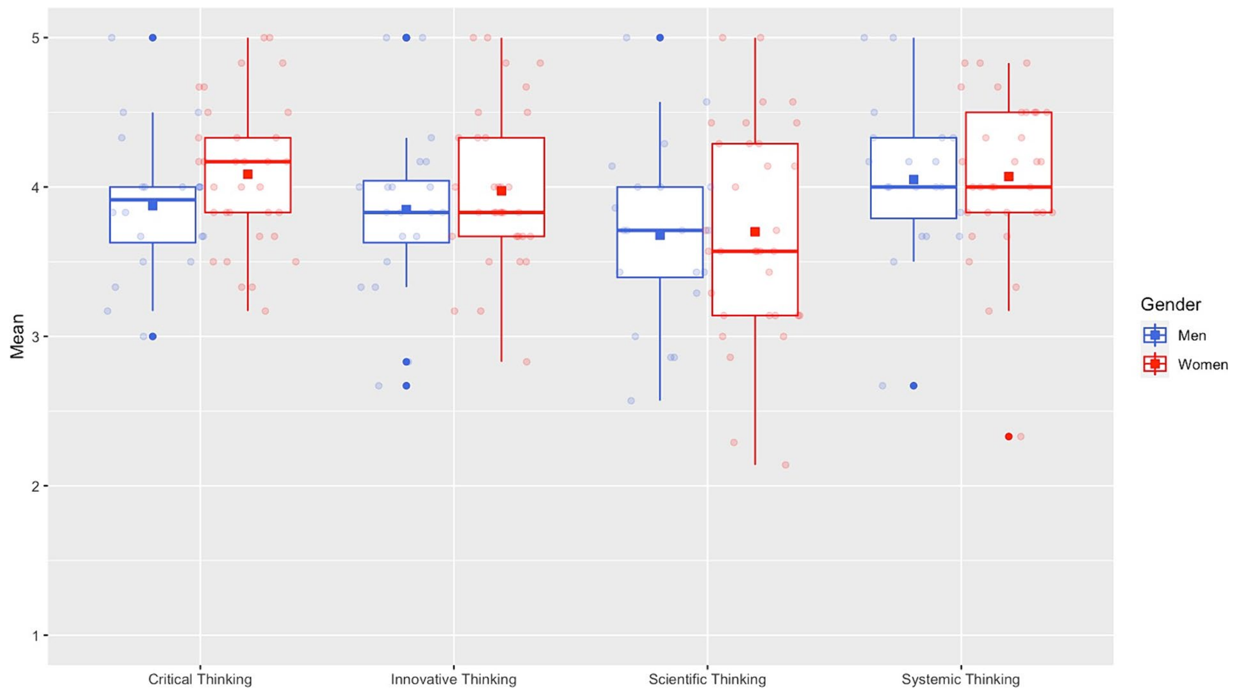

FIGURE 1
Complex thinking: box-plot analysis by gender.

TABLE 3 Complex thinking: *T*-test analysis.

	t	Df	p-value
Systemic thinking (men and women)	−0.14	41.18	0.88
Scientific thinking (men and women)	−0.12	45.35	0.90
Critical thinking (men and women)	−1.54	41.77	0.13
Innovative thinking (men and women)	−0.78	37.40	0.43
Complex thinking (men and women)	−0.66	41.10	0.50

*Statistical significance difference between the perceptions in developing complex thinking by gender ($p \leq 0.05$).

figure is the notable presence of outliers in the lower quartile among students from the Schools of Architecture, Business, and Engineering. This pattern suggests that within these disciplines, there is a significant variation in how students rate their development of complex thinking skills. Some students perceive themselves as much less developed in these areas compared to the majority of their peers. This could point to potential gaps in the curriculum or pedagogical approaches within these schools that might not adequately support or challenge students in developing these crucial skills. Additionally, the presence of these outliers prompts further investigation into the specific aspects of the educational environments in these disciplines. Factors such as the teaching methods employed, the emphasis on practical vs. theoretical learning, and even the student–teacher interactions could play critical roles in shaping these perceptions.

To thoroughly investigate whether students' perceptions of their complex thinking skills vary significantly across different schools and disciplines, we employed a statistical *t*-test, with the detailed results presented in Table 4. The application of this statistical method allowed us to compare mean values of self-perceived complex thinking competencies among students from various academic backgrounds to ascertain if there were any notable differences attributable to their specific educational environments. The findings from the *t*-test revealed that there were no statistically significant differences in how students across different schools rated their development in complex thinking skills. This uniformity in self-perception suggests a consistent level of educational support and curriculum effectiveness in fostering complex thinking across the disciplines surveyed. It implies that despite the inherent differences in curriculum focus and teaching methods among schools—such as those dedicated to engineering, humanities, or sciences—the impact on students' self-assessment of critical cognitive skills like analysis, synthesis, and evaluation remains comparable. This outcome is significant as it may indicate that efforts to integrate complex thinking into the curricula are being implemented with a degree of uniformity and effectiveness across disciplines. However, the lack of variation also prompts further questions about the sensitivity of the measurement tools used or the potential ceiling effects in the survey responses. It could be beneficial for future research to employ a more differentiated approach or more sensitive instruments to capture subtle differences that might exist.

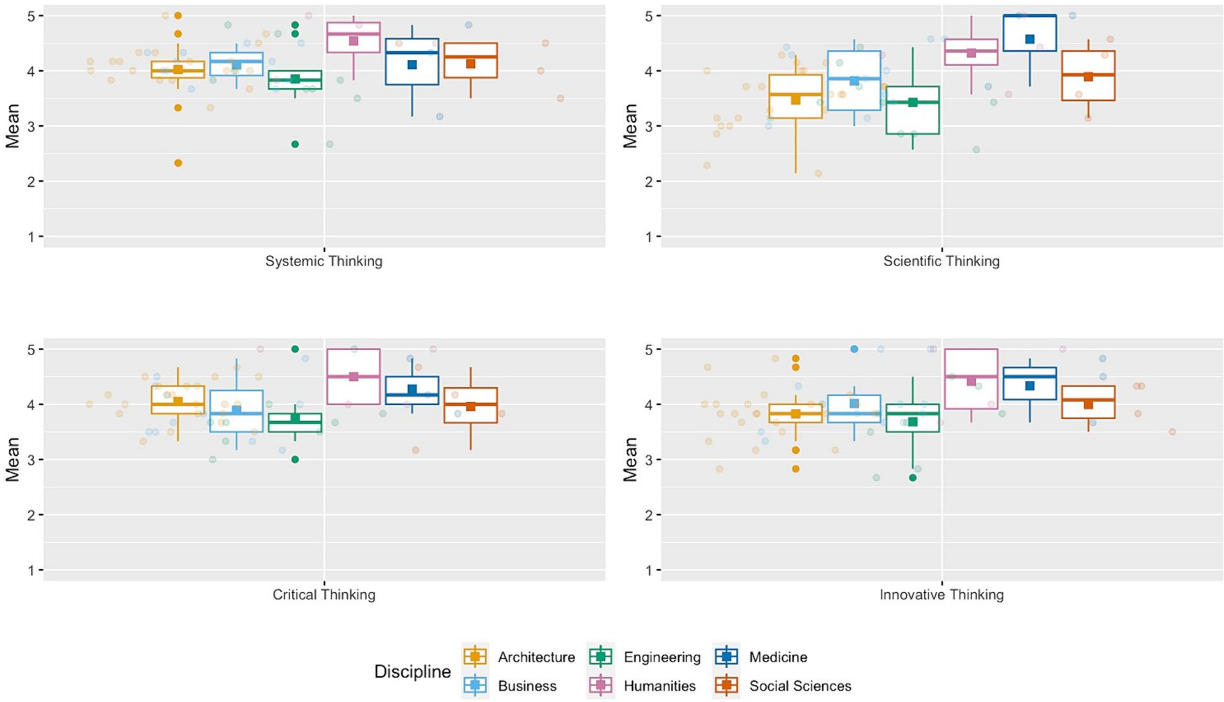

FIGURE 2
Complex thinking: box-plot analysis. Sub-competencies by discipline.

TABLE 4 Complex thinking: *T*-test analysis.

p-value	Humanities	Social Sciences	Medicine	Business	Engineering	Architecture
Humanities	1.00	–	–	–	–	–
Social sciences	0.28	1.00	–	–	–	–
Medicine	0.81	0.52	1.00	–	–	–
Business	0.18	0.90	0.45	1.00	–	–
Engineering	0.06	0.34	0.23	0.21	1.00	–
Architecture	0.11	0.58	0.33	0.36	0.44	1.00

*Statistical significance differences in students' perceived development of complex thinking by discipline ($p \leq 0.05$).

Figure 3 employs box plots to effectively depict the dispersion of students' self-perception regarding complex thinking sub-competencies, segmented by their academic semester. This graphical representation particularly emphasizes the variations among students in their fifth semester, where a broader spread in scores across all sub-competencies is observed. Notably, there is a higher concentration of lower quartile values, suggesting that these students might be experiencing greater variability or challenges in their development of complex thinking skills at this stage in their education.

Table 5 provides an analytical breakdown through a *t*-test analysis of the mean values of students' perceived complex thinking abilities, categorized by semester. The results from this analysis reveal that students in their sixth semester demonstrate statistically significant differences in their self-perceptions compared to peers in other semesters. This suggests that something distinct occurs at this educational phase which might influence how students assess their own complex thinking capabilities, possibly reflecting curricular changes, increased academic demands, or other educational interventions that occur at this point in their academic journey.

Table 6 outlines the mean values and standard deviations concerning students' perceptions of using Artificial Intelligence (AI) tools. The data shows an overall mean of 3.81, indicating a generally positive openness and adoption of these tools among the students. They particularly excel in their perception of utilizing these technologies within their professional settings, with a mean score of 4.10, suggesting a high degree of integration and reliance on AI tools in practical applications. However, there appears to be some reservation, as indicated by a lower mean of 3.66, regarding whether the knowledge of these AI tools should be formally incorporated into professional training processes. This discrepancy highlights a potential area for academic and professional debate concerning the role and depth of AI technology integration in educational curricula.

Figure 4 utilizes a box-plot analysis to graphically represent the variation in students' perceptions of using AI tools, with a distinction

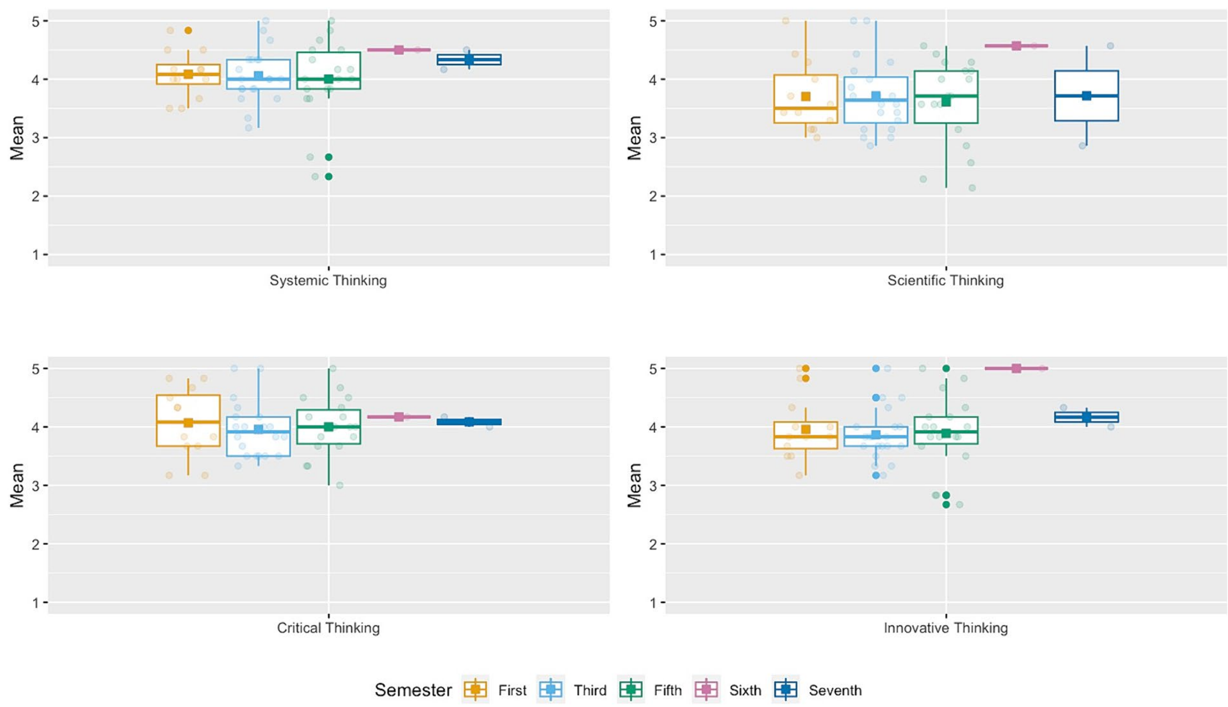

FIGURE 3
Complex thinking: box-plot analysis—sub-competencies by semester.

TABLE 5 Complex thinking: *T*-test analysis.

p-value	First	Third	Fifth	Sixth	Seventh
First	1.00	–	–	–	–
Third	0.74	1.00	–	–	–
Fifth	0.67	0.87	1.00	-	–
Sixth	0.00*	0.00*	0.00*	1.00	–
Seventh	0.79	0.70	0.66	0.38	1.00

*Statistical significant differences in students' perceived development of complex thinking by semester ($p \leq 0.05$).

TABLE 6 Artificial intelligence: mean and standard deviation values—total and by gender.

	Men		Women		Total	
	Mean	SD	Mean	SD	Mean	SD
Attitude toward AI	3.70	0.78	3.67	0.77	3.67	0.76
Understanding of AI	3.89	0.69	3.65	0.62	3.74	0.65
Attitude toward teaching	3.73	1.01	3.62	0.68	3.66	0.81
Readiness in the critical use of AI	4.10	0.53	4.10	0.59	4.10	0.56
Total	3.88	0.49	3.77	0.44	3.81	0.45

made between genders. The analysis reveals that men reported higher mean values across most dimensions, indicating a greater openness to adopting and using these tools. However, an interesting observation is that both men and women reported equal mean values (4.10) for their training in the critical use of artificial intelligence, suggesting a gender-neutral perception in this specific area of competence.

Table 7 details the results of a *T*-test analysis that examines potential gender differences in self-perception concerning the use of AI tools across various dimensions. The findings show that there are no statistically significant differences between men and women in how they perceive their usage of these tools. This lack of disparity underscores a uniform acceptance and integration of AI technology across gender lines within the student population.

Figure 5 presents a box-plot analysis that illustrates students' perceived use of AI tools, segmented by dimension and academic discipline. Notably, the data for students in the School of Architecture

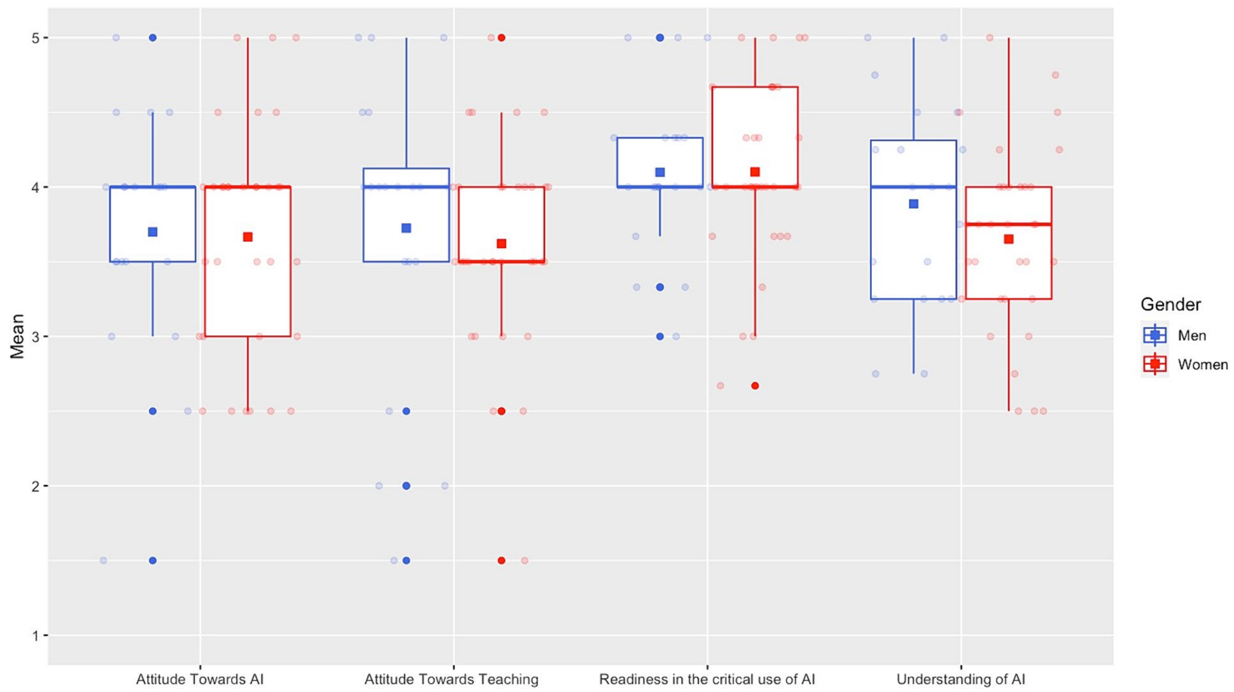

FIGURE 4
Artificial intelligence: box-plot analysis by gender.

TABLE 7 Artificial intelligence: *T*-test analysis.

	t	Df	*p*-value
Attitude toward AI (men and women)	0.15	39.51	0.88
Understanding of AI (men and women)	1.25	37.167	0.21
Attitude toward teaching (men and women)	0.40	29.77	0.68
Readiness in the critical use of AI (men and women)	−0.01	43.38	0.98
Total (men and women)	0.82	36.43	0.41

*Statistically significant differences in students' perceived development of artificial intelligence competency by gender ($p \leq 0.05$).

show a distinct pattern of outliers in the lowest quartile across all dimensions of the instrument, suggesting that these students might feel less proficient or less integrated with AI technologies compared to their peers in other disciplines.

Table 8 provides the results of a *T*-test analysis aimed at identifying any significant disciplinary differences in students' perceptions regarding the use of AI tools. The analysis indicates significant differences between students in the Humanities and those in the medical and business disciplines. Additionally, there were notable differences between students in Architecture and their counterparts in Medical, Business, and Engineering fields. These findings suggest that perceptions of AI tool usage can vary widely across disciplines, likely influenced by the specific curricular focus and the prevalence of AI integration within different academic programs.

Figure 6 provides a detailed visual representation of the relationship between students' academic semester and their perception of using artificial intelligence (AI) tools. It highlights that students in their third and fifth semesters exhibit a wide dispersion in their perceptions, primarily concentrated in the first quartile, suggesting relatively low levels of openness to AI tools. Conversely, students in their first and sixth semesters report higher mean values, 3.86 and 4.00 respectively, indicating a more positive perception of AI tool usage. Notably, students in their seventh semester demonstrate the lowest mean perception value at 3.68, reflecting a more critical stance toward the use of these tools and their integration into professional training.

A *T*-test analysis was conducted to ascertain if there were statistically significant differences in the mean perceptions of students about using AI tools across different semesters. The results, calculated with a significance threshold $p \leq 0.05$, showed no statistically significant differences. This suggests that, overall, students' perceptions do not vary markedly by semester, indicating a generally consistent view of AI tools throughout their academic progression.

Figure 7 introduces a scatter plot enhanced with a linear regression line to investigate the potential relationship between students' perceived level of complex thinking and their use and adoption of AI tools in professional settings. The positive slope of the regression line reveals a positive correlation between these two variables, suggesting that students who perceive themselves as having stronger complex thinking skills are also more likely to adopt and utilize AI technologies effectively. This correlation underscores the importance of cultivating

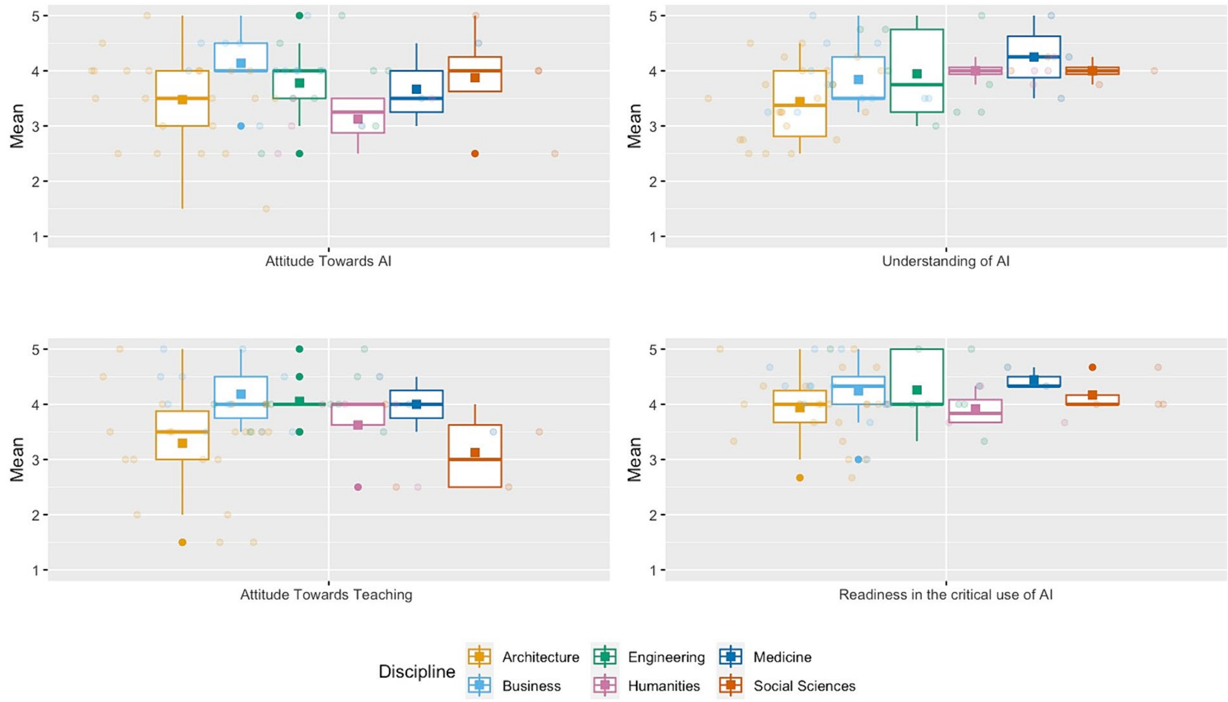

FIGURE 5
Artificial intelligence: box-plot analysis—sub-competencies by discipline.

TABLE 8 Artificial intelligence: *T*-test analysis.

p-value	Humanities	Social sciences	Medicine	Business	Engineering	Architecture
Humanities	1.00	–	–	–	–	–
Social Sciences	0.64	1.00	–	–	–	–
Medicine	0.02*	0.24	1.00	–	–	–
Business	0.05*	0.40	0.43	1.00	–	–
Engineering	0.13	0.53	0.34	0.77	1.00	–
Architecture	0.21	0.23	0.00*	0.00*	0.01*	1.00

*Statistically significant differences between students' perceptions of developing artificial intelligence competency by discipline ($p \leq 0.05$).

complex thinking as a foundational skill that can enhance students' ability to engage with and benefit from advanced technological tools.

5 Discussion

5.1 Main findings of this work

In general, participants perceived that using AI tools will play a determining role in their profession and that, therefore, having knowledge and preparation for the professional use and adoption of these tools would be professionally relevant. However, they question the teaching of these tools in the curriculum of all students in their profession. In this sense, it is possible to appreciate a contradiction because, on the one hand, they perceive the need, but on the other hand, they do not consider that it should be adopted as an element of their profession. These results are consistent with previous research regarding students' perceptions of the use of these types of tools, where the relevance that AI can have in professional development is recognized (Utami et al., 2023). However, a recurring concern in various studies is the implications of using these tools in their professions, both in terms of data management, privacy, and other ethical dilemmas (Almaraz-Menéndez and López-Esteban, 2023). In this regard, it is necessary to delve deeper into these concerns of AI users, as this could influence the less favorable views of its inclusion in education.

As for the relationship of this result with their perceived competency of complex thinking, it was possible to argue that there is indeed a relationship between critical thinking and systemic thinking, the sub-competencies that seem to have the most influence on the positive perception of using and adopting AI tools at the professional level. This has been previously considered by Arli et al. (2023), who emphasize how ethical and integrated training in the use of AI tools can be an excellent opportunity to develop research and critical thinking skills in students.

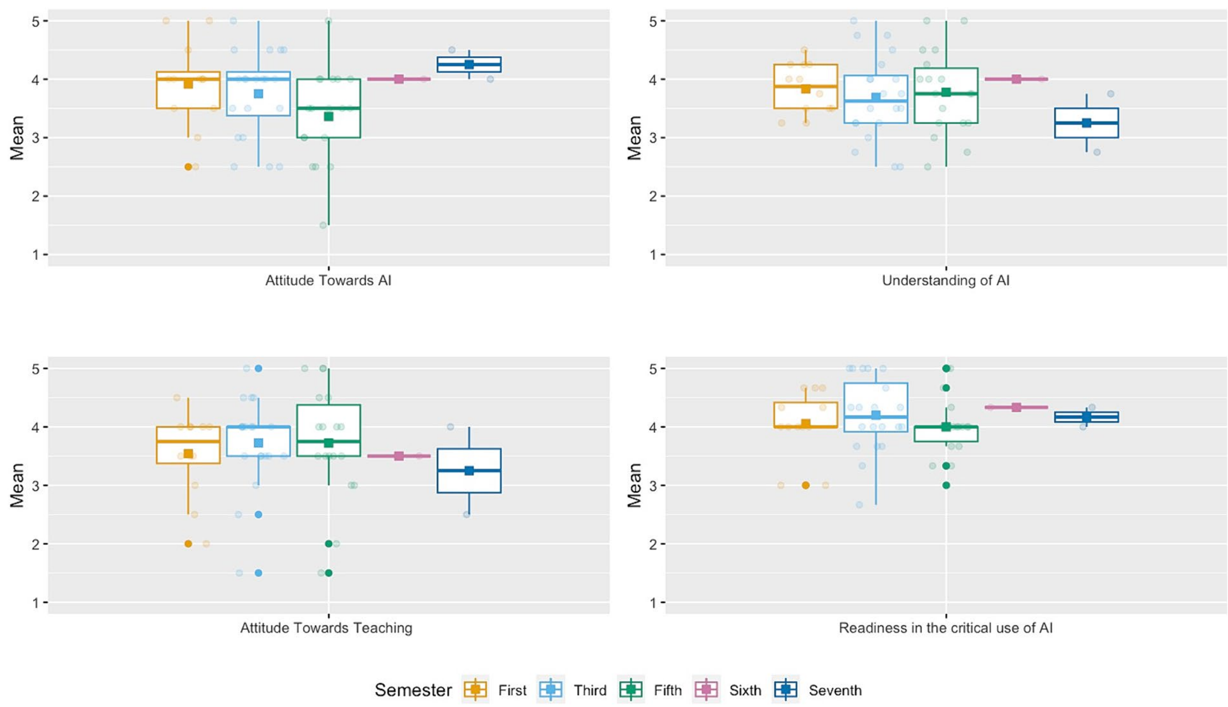

FIGURE 6
Artificial intelligence: box-plot analysis—sub-competencies by semester.

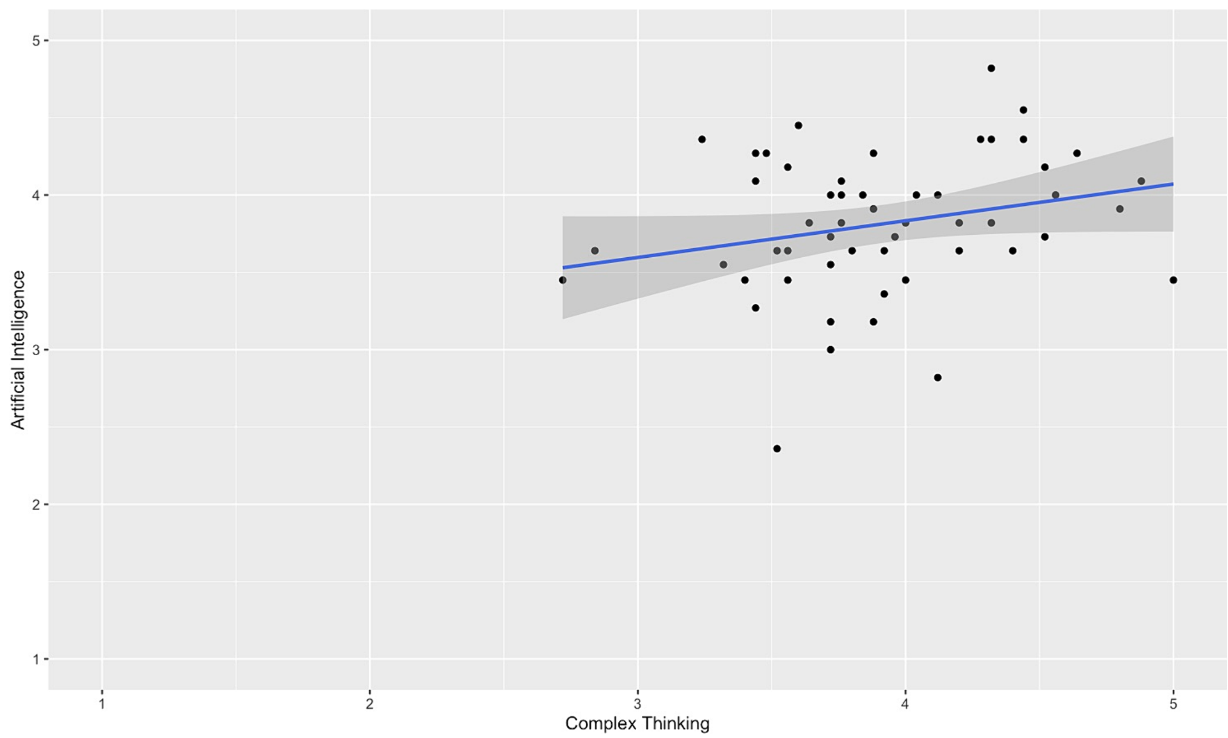

FIGURE 7
Complex thinking and artificial intelligence: scatter plot with linear regression line.

However, gender did not influence students' perceived use and adoption of AI tools in the profession because, despite the differences between men and women and the variances in perceived achievement of complex thinking, none were statistically significant. This result is contradictory to previous studies such as that of Mendonça de Lima et al. (2023), who not only identify a difference in use based on gender, but also find social, technical and individual biases that influence this differentiated perception.

Regarding the participants' disciplines, the medical students had the best perception regarding using and adopting AI tools in their professions, in contrast to their colleagues in Architecture, Art, and Design. This result contradicts their perceived achievement of complex thinking because Humanities was the discipline with the best perception. However, it is essential to note that the perception of achievement did not show statistically significant differences and that, although Medicine was not the discipline with the best mean, its level of perception was high. Something interesting about this indicator is that Medicine had the highest level of perceived scientific thinking, while Architecture, Art, and Design was one of the lowest in this sub-competency, so it would be essential to analyze whether, concretely, this sub-competency could be determinant, beyond the general average of the perception of the competency. These disciplinary differentiations have been previously addressed by studies such as Shinners et al. (2021) or Fang et al. (2023), who identify that the use and perceived use of AI tools may be different for students in health sciences or law in contrast to professionals in other disciplines.

Finally, considering the semester, sixth-semester students had the best perception of adopting AI tools and the highest perceived development of complex thinking and all its sub-competencies. Interestingly, final-year students showed the most critical perception of adopting these tools, especially regarding the general attitude toward their professional use. Delving into this point would be very important because, although it can be presumed that this may result from a perception of uncertainty about the changes in their professions with little time to adopt these new tools, this negative perception could be addressed with appropriate training interventions.

5.2 Theoretical and practical implications

There is no doubt that educational institutions have an increasing interest in adopting tools with artificial intelligence in the curricula of their professional offerings; however, it cannot be limited to including this technology as if it were software because the professional implications go beyond that. The use and adoption of tools with artificial intelligence is proposed not only as an improvement in professional processes but, in some cases, as an evolution in how things are done in some professions. In this sense, identifying a possible relationship between the adoption and openness of these tools by students with cognitive skills such as complex thinking and their sub-competencies has clear, practical implications for educational institutions, especially for pedagogical interventions associated with semesters or disciplines in which there is some resistance and questioning of these new technologies.

Theoretically, these results support existing studies on complex thinking, providing a relationship between the development of this competency and the appropriate adoption of artificial intelligence tools. Furthermore, these results elevate the importance of doing more studies associated with the perception of potential users of these technologies, considering that the adoption of this knowledge by institutions is not enough if students are not first prepared with the necessary skills for adequate adoption and understanding.

5.3 Limitations

The use of accessible AI tools by the population is a relatively recent development, and as such, associated studies are primarily exploratory and come with inherent limitations. The present study, while yielding valuable insights, is not without its constraints. First, the study's sample size is limited, involving only a small population from a single educational institution. This restricts the generalizability of the findings to broader educational contexts. Second, the instruments used in the study primarily focus on the participants' perceptions rather than providing objective measurements of complex thinking and its sub-competencies. This subjective approach may introduce bias and limit the accuracy of the findings regarding the actual competency levels. Despite these limitations, the exploratory nature of the study offers significant value, highlighting the potential for further research in this area, particularly within the educational field, and underscoring the need for more comprehensive and diverse studies in the future.

5.4 Future lines of research

It remains to analyze in greater depth the contradiction identified in the results between men and women, as well as the difference between the positive perception of the professional adoption of these tools and the questioning of their inclusion in professional training programs. In addition, it would be relevant to broaden the population of the different disciplines or to carry out specific studies to identify specific relationships between training, sub-competencies of complex thinking, and the perception of the adoption and use of artificial intelligence tools. Finally, it would be helpful to delve deeper into why the about-to-graduate students are the most critical of this technology, mainly because of the implications that this may have on universities in the short term.

6 Conclusion

This article proposed a possible relationship between students' perceived use, adoption, and professional training of AI tools and their perceived achievement of complex thinking competency and its sub-competencies. The motivation was based on the principle that this competency allows the development of a broader perception of uncertain environments, which may indirectly influence the assessment of the adoption of new technologies. In conclusion, the results identified a particular relationship between both elements, although, as noted above, this was an exploratory study; therefore, the findings are not exhaustive. Even so, we believe that the most valuable contribution of this article lies in the broad possibilities for more studies, as it identifies relevant elements that should analyzed in greater depth.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: The raw data supporting the conclusions of this article will be made available by the authors, without, undue reservation.

Requests to access these datasets should be directed to cruzsandovalmarco@tec.mx.

Ethics statement

The studies involving humans were approved by the Institute for the Future of Education, Tecnologico de Monterrey, Mexico. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

JV-P: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. CG-G: Conceptualization, Formal analysis, Investigation, Supervision, Validation, Writing – original draft, Writing – review & editing. JA-Z: Conceptualization, Formal analysis, Investigation, Supervision, Validation, Writing – original draft, Writing – review & editing. AC: Conceptualization, Formal analysis, Investigation, Supervision, Validation, Writing – original draft, Writing – review & editing. SP-G: Conceptualization, Data curation, Formal analysis, Investigation, Supervision, Validation, Writing – original draft, Writing – review & editing. MC-S: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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