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Research Article

Serious games and complex thinking: A study on gender differences and study discipline in university students

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ABSTRACT

Serious games are a fundamental tool to promote learning in a playful way and to develop a wide range of cognitive skills such as complex thinking. In this study we sought to first analyze the perceived achievement of complex thinking sub-competencies by majors, and we also aimed to investigate mean differences in the group of students coming from computer science and engineering related majors and by gender of the participants in complex thinking sub-competencies. 417 learners were part of this study, of which 65.7% were male and 34.3% were female. It was found that medical students perceived higher achievement in systems, scientific and innovative thinking, while data science and industrial engineering students excelled in critical thinking. Statistically significant differences were found between engineering and computer science careers and systemic thinking, being higher in engineering. Likewise, significant differences by gender were found in all sub-competencies except innovative thinking, where women outperformed men. The findings are discussed in light of the evidence in the literature on the subject.

Keywords: serious games, complex thinking, higher innovation in education, future of education, gender differences

INTRODUCTION

The challenges of the 21st century–such as climate change, digital transformation, and social inequalities–demand professionals capable of addressing problems from multidimensional, creative, and systemic perspectives (Macías-Galeas, 2024; Trevisan et al., 2023). Within this framework, complex thinking is conceived as a meta-competence that integrates diverse forms of reasoning necessary to understand and act effectively in uncertain and dynamic contexts. According to Ramírez-Montoya et al. (2024), complex thinking is composed of four interrelated sub-competencies.

Systemic thinking enables individuals to analyze phenomena from a holistic standpoint, recognizing interrelationships and the consequences of actions within dynamic systems (Capra & Luisi, 2014). Scientific thinking involves observation, hypothesis formulation, and evidence-based evaluation to solve problems with rigor and objectivity (Tobón & Luna-Nemecio, 2021). Critical thinking entails questioning, contrasting, and arguing ideas on logical and ethical grounds, thereby strengthening intellectual autonomy (Facione, 2020;

Paul & Elder, 2019). Finally, innovative thinking combines creativity with transformative action, promoting the generation of original and sustainable solutions (Ramírez-Montoya & Portuguez-Castro, 2024).

Together, these sub-competencies foster a comprehensive understanding of reality and enhance individuals' ability to learn, adapt, and transform their environment from critical, scientific, and creative perspectives. Developing these abilities allows learners to interpret uncertainty, establish interdisciplinary connections, and make sustainable decisions in evolving contexts (Acevedo-Rueda et al., 2020; Tobón & Luna-Nemecio, 2021). Consequently, promoting complex thinking in higher education has become a strategic goal for cultivating reflective, creative, and socially responsible professionals aligned with the sustainable development goals (SDGs) (Costa et al., 2024; Xing & Ironsi, 2024).

Nevertheless, such training remains largely absent in many curricula, and discourses related to education for sustainable development are seldom integrated into educational practice (Costa et al., 2024). Embedding the development of high-level competencies–such as complex thinking–into engaging learning experiences, for example through gamification strategies, can facilitate critical analysis of global challenges and stimulate the creation of innovative and sustainable solutions (Angelelli, 2023; Hallinger et al., 2020; Irabor et al., 2025).

In parallel, the digital transformation of education has accelerated the adoption of serious games, defined as digital environments designed not only for entertainment but also for learning and competency development (Dörner et al., 2016; Michael & Chen, 2006). Grounded in constructivist and experiential learning theories (Gee, 2007; Kolb, 1984), serious games promote active participation, reflection, and decision-making within simulated contexts that reproduce the complexity of real-world situations (Buijs-Spanjers et al., 2018; López-Serrano et al., 2025).

The psychological theories of self-determination (Deci & Ryan, 2000) and flow (Csikszentmihalyi, 1990) provide a relevant theoretical framework for understanding how serious games foster motivation and learner immersion, thereby enhancing academic engagement and learning outcomes. Self-determination theory posits that intrinsic motivation–arising from personal interest and satisfaction–is strengthened when three basic psychological needs are met: *autonomy, competence,* and *relatedness*. Educational environments that encourage decision-making, skill mastery, and social interaction foster a sense of agency and belonging, which in turn enhances active engagement.

Complementarily, flow theory describes an optimal psychological state of concentration and enjoyment that occurs when activities balance challenge and skill, establish clear goals, and provide immediate feedback. In this state, learners become deeply immersed in the learning experience, exhibiting sustained motivation, pleasure, and focused attention.

Together, these frameworks explain why serious games are particularly effective for promoting meaningful learning: by satisfying psychological needs and maintaining students in immersive states, they channel motivation toward problem-solving, collaboration, and systemic reasoning. Consequently, serious games have been increasingly adopted to foster transversal competencies across various educational contexts (Gürbüz & Çelik, 2022; Luhova, 2021).

A growing body of research suggests that serious games constitute an effective and transformative pedagogical tool, often outperforming conventional instructional methods (Arosquipa-Lopez et al., 2024; Wouters et al., 2013). López et al. (2021) emphasize that the intention to use such tools is influenced by performance expectations, highlighting their potential for professional training. Empirical studies across diverse fields–such as health, education, culture, and well-being–have shown that serious games enhance knowledge, skills, and attitudes through active and immersive experiences (Din et al., 2023).

Recent findings further indicate that serious games can stimulate higher-order cognitive processes associated with complex thinking (Noh et al., 2024; Voorhis, 2019). For example, Lala et al. (2019) demonstrated that dialogic interactions with virtual agents in the *communicate* game foster critical and reflective thinking. Similarly, Pacheco-Velázquez (2024) examined the effects of an educational platform, a serious game, and other instructional resources on the development of self-directed learning, critical thinking, and complex thinking, reporting significant improvements in academic indicators and intrinsic motivation.

Within the framework of Industry 4.0, Pacheco-Velázquez et al. (2024) incorporated a serious game-based approach into logistics education to strengthen complex thinking competencies and practical skills linked to the sector's digital transformation. Complementary studies by Markopoulos and Markopoulos (2023) and Stanitsas et al. (2019) demonstrated that serious games and virtual reality technologies can advance the SDGs and foster understanding of sustainability challenges by cultivating sub-competencies such as systemic thinking and strategic planning.

These results align with broader evidence showing that serious games encourage analysis, decision-making, and reflection on one's actions–core processes of complex thinking. However, few studies have directly examined the relationship between serious game engagement and the development of complex thinking competencies in higher education contexts.

Beyond cognitive outcomes, it is essential to understand how individual characteristics influence the development of complex thinking. Previous studies on gender differences suggest that men and women perceive their mastery of this meta-competence differently, though findings remain inconclusive. For instance, Alonso-Galicia et al. (2024) reported that women perceived higher levels of achievement in complex thinking sub-competencies compared to men, despite no significant differences in the overall meta-competence.

Regarding disciplinary variation, students in engineering and computer science programs are typically exposed to problem-solving and systemic reasoning scenarios, which may foster the development of complex thinking (George et al., 2024). Also, students in medicine and health sciences are those who tend to get higher scores in the sub-competences of complex thinking (Suárez-Brito et al., 2024), and in engineering students the higher results are presented in systems thinking sub-competences (Vázquez-Parra et al., 2023). Nonetheless, the intersection between gender, academic discipline, and exposure to serious games remains an underexplored domain, with potential to generate evidence on how learning experience design can advance more inclusive, equitable, and effective higher education practices.

Although multiple studies have documented the benefits of serious games for active learning, motivation, and skills acquisition (Cheng et al., 2015; Din et al., 2023; Moradi & Noor, 2022), empirical evidence directly linking serious games to the development of complex thinking and its sub-competencies remains limited–particularly in analyses considering gender and disciplinary differences.

Likewise, the use of logistics simulators as learning tools for promoting higher-order cognitive skills has received relatively little scholarly attention (Pacheco-Velázquez, 2024). That study demonstrated significant gains in academic performance, motivation, and engagement, suggesting strong potential. However, further exploration is needed to elucidate how serious games contribute to the development of complex competencies, particularly within digital and applied learning environments. Addressing this gap may provide valuable empirical evidence for educational innovation and curriculum transformation in higher education.

Research Objective and Hypotheses

Accordingly, this study aims to analyze university students' perceived achievement of complex thinking sub-competencies (systemic, scientific, critical, and innovative thinking) after their participation in a logistics simulator (V-Logistics), considering differences by gender and field of study.

H1: Students enrolled in engineering and computer science programs will report higher perceived achievement in complex thinking sub-competencies.

H2: Female students will report higher perceived achievement in complex thinking sub-competencies than male students.

From a theoretical perspective, this study advances conceptual understanding of the relationship between game-based learning and complex thinking, providing empirical evidence on how digital tools can strengthen essential meta-competencies for sustainability, problem-solving, and lifelong learning. From a practical standpoint, the findings may inform curriculum design and educational innovation in higher education, identifying strategies and technologies that promote equity, motivation, and interdisciplinary thinking. Ultimately, this research contributes to the transformation of pedagogical practices, preparing students to face the complex and interconnected challenges of contemporary society.

Table 1. Frequency (n) and percentage (%) of demographic data of the study sample

Variable	Variable	Frequency (n)	Percentage (%)
Gender	Male	274	65.7
	Female	143	34.3
Study program	International business	39	9.4
	Data science and mathematics engineering	27	6.5
	Industrial engineering	39	9.4
	Computer engineering	60	14.4
	Computer sciences	12	2.9
	Civil engineering	8	1.9
	Data science	21	5.0
	Medicine	26	6.2
	Industrial and systems engineering	33	7.9
	Systems analysis and development	32	7.7
	Information systems	5	1.2
University	Tecnologico de Monterrey	219	52.5
	Mackensie	38	9.1
	Instituto Uno	5	1.2
	Universidad Presbiteriana	31	7.4
	UNIVA	38	9.1
	Universidad de la Frontera	43	10.3
Education level	Bachelor	345	82.7
	High school	43	10.3
	PhD	19	4.6
	Master	10	2.4

METHOD

Type of study

A quantitative cross-sectional study of comparative scope was carried out.

Participants

A total of 417 participants were selected on a non-probabilistic basis, of which 65.7% were men and 34.3% were women. In terms of career, a variety of disciplines were covered, ranging from international business (9.4%) and medicine (6.2%) to computer engineering (14.4%) and data science (5.0%). The sample comes from several universities, with Tecnologico de Monterrey being the most represented with 52.5%, followed by Universidad de la Frontera with 10.3%. Regarding educational level, most of the participants have a bachelor's degree (82.7%), followed by those with a high school education (10.3%) (**Table 1**).

Data Collection and Analysis

The study uses a logistics simulator called V-Logistics, which is hosted on an educational platform where open educational resources, other simulation games and educational videos on logistics concepts can be found to support to better understanding of the game. The V-Logistics simulator recreates the operations of a ball manufacturing company. Players manage a factory and a store, making decisions regarding production, selection of raw materials and suppliers, and shipping of products. Randomized data sets are used to simulate real-life situations, allowing participants to analyze various aspects such as demand, production capacity, raw material availability and delivery times to maximize economic profit. Although some elements of the game are simplified, such as the absence of defective products and the setting of supplier lead times, it is expected that players will recognize the importance of these data for decision making. Although the profitability of each product is not explicitly provided, it is anticipated that players will be able to infer it from the data provided. Outcomes and random events influence future decisions, promoting strategic and adaptive thinking in participants. The users of the V-Logistics simulator, once they used the platform, voluntarily answered the scale, which had an approximate response time of 15 minutes. Once the data was collected, we proceeded to clean the missing data and analyze the data with the support of SPSS version 25 statistical software in which descriptive data and comparisons of means were calculated to respond to the research objectives.

Table 2. Mean (M) and standard deviation (SD) of complex thinking sub-competencies by career of study

	Systemic thinking		Scientific thinking		Critical thinking		Innovative thinking	
	M	SD	M	SD	M	SD	M	SD
International business	3.73	0.46	3.64	0.60	3.83	0.53	3.87	0.60
Data science and mathematics engineering	4.09	0.34	3.79	0.61	4.07	0.48	3.97	0.50
Industrial engineering	3.89	0.43	3.68	0.65	4.07	0.44	3.99	0.53
Computer engineering	3.93	0.70	3.69	0.76	3.84	0.77	3.87	0.78
Computer science	3.94	0.29	3.72	0.35	3.88	0.24	3.85	0.31
Civil engineering	4.04	0.16	3.97	0.27	3.96	0.41	3.96	0.41
Data science	3.98	0.64	3.63	0.68	3.79	0.66	3.75	0.77
Medicine	4.13	0.52	3.91	0.64	4.04	0.49	4.08	0.62
Industrial and systems engineering	4.02	0.43	3.66	0.62	3.95	0.51	4.06	0.70
Systems analysis and development	3.79	0.67	3.63	0.69	3.81	0.66	3.72	0.70
Information systems	2.95	0.37	3.06	0.49	2.82	0.40	3.05	0.69

The Scale

e-Complexity scale

The e-Complexity instrument (Castillo-Martínez & Ramírez-Montoya, 2022), which measures complex reasoning competence, was applied. The instrument is composed of 25 items grouped into four dimensions that assess the sub-competencies of complex thinking: systems thinking (8 items, e.g., I am inclined to use strategies to understand the parts and the whole of a problem); scientific thinking (6 items, e.g., I am inclined to use scientific data to analyze research problems, e.g., I am inclined to use scientific data to analyze research problems, e.g., I am inclined to use scientific data to analyze research problems. I am inclined to use scientific data to analyze research problems); critical thinking (7 items, e.g., I use reasoning based on scientific knowledge to make judgments about a problem); and innovative thinking (4 items, e.g., I analyze research problems considering the context to create solutions). The Scale has a Likert-type response format with values ranging from 1, "do not agree at all" to 5 "strongly agree." The scale presents reliability values by Cronbach's alpha and McDonald's omega coefficient above the values suggested in the literature (Green, 2015) both in its dimensions and globally.

FINDINGS

Table 2 provides data on the mean (M) scores and standard deviations (SDs) in the sub-competencies of complex thinking: systemic, scientific, critical, and Innovative for different study careers of the study participants, the findings show that, in systemic thinking, medicine obtained the highest score (M = 4.13, SD = 0.52), followed by data science engineering and mathematics (M = 4.09, SD = 0.34). For scientific thinking, students of civil engineering (M = 3.97, SD = 0.27) and medicine also (M = 3.91, SD = 0.64) obtained higher means compared to the rest of the study majors. Regarding critical thinking, data science and mathematics engineering and industrial engineering students obtained higher means (M = 4.0, SD = 0.48 and M = 4.0, SD = 0.44). On the other hand, medical students also lead in the mean in the innovative thinking sub-competency (M = 4.08, SD = .62) followed by industrial and systems engineering students (M = 4.06, SD .70).

The findings suggest that different areas of study present gaps in the development of complex thinking sub-competencies in their students, except for medical students who excel in all complexes thinking sub-competencies, indicating that these students receive solid training in systemic, scientific, critical and innovative thinking. For the rest of the careers, these findings can be a starting point to analyze and adapt curricula and teaching methods to promote more holistic thinking in disciplines such as engineering or computer science that allow students to have the competencies to face complex challenges with a variety of cognitive skills.

Table 3 shows the comparisons of means in the sub-competences of complex thinking with the group of careers related to computing and those related to engineering, it was found that there are only statistically significant differences in the sub-competence of systemic thinking, being the group of students of engineering careers those who present a higher percentage, of the rest of the sub-competences no statistically significant differences were found.

Table 3. Differences in means between the sub-competencies of complex thinking and computer and engineering group

	Computation	Engineering	t	p
Systemic thinking	3.79	3.98	-2.140	.03
Scientific thinking	3.67	3.54	1.230	.18
Critical thinking	3.87	3.89	-.261	.79
Innovative thinking	3.81	3.78	.325	.74

* $p < .05$

Table 4. Mean differences between complex thinking sub-competencies and sex of study participants

	Male	Female	t	p
Systemic thinking	3.88	4.00	-2.030	.04
Scientific thinking	3.67	3.75	-1.210	.02
Critical thinking	3.83	3.99	-2.540	.01
Innovative thinking	3.84	3.97	-1.750	.06

* $p < .05$

The results show that, although there are similarities between computer science and engineering careers in the sub-competencies of complex thinking, engineering students show a greater development in systems thinking, this highlights the need to focus on strengthening systems thinking in the curriculum of computer science careers, an effective strategy could be interdisciplinary collaboration between different fields or areas of knowledge.

Table 4 shows the comparisons of means of the sub-competences of complex thinking and the sex of the participants in the study, statistically significant differences were found in all the sub-competences except for innovative thinking, in the sub-competences in which significant differences were found, women presented higher means compared to men.

The results reveal that women may have an advantage in the development of skills related to complex thinking compared to men. Therefore, this suggests the importance of curricula considering the gender variable when designing study plans and programs, this demonstrates the need to promote equal opportunities for both sexes to develop to their full potential the sub-competencies of complex thinking.

DISCUSSION

Serious games are central to the development of advanced cognitive competencies because of their ability to intrinsically motivate players, provide hands-on and personalized learning experiences, and challenge a wide range of cognitive skills. The study analyzed students' perceived mastery of complex thinking sub-competencies, analyzed mean differences in the achievement of complex thinking sub-competencies by group of computer science and engineering majors, and analyzed mean differences in the achievement of complex thinking sub-competencies between male and female participants in the study.

Table 2 reports the findings on the students' perception of their level of achievement in the sub-competences of complex thinking, the students of medicine are those who consider that their level of achievement is higher in the sub-competences of systemic, scientific, and innovative thinking, the students of data science and mathematics engineering and industrial engineering stood out in critical thinking. Our findings are consistent with what has been reported in the literature on the subject, in which it is reported that students of professional careers in medicine and health sciences are those who obtain higher scores in the sub-competences of complex thinking (Suárez-Brito et al., 2024). For the rest of the careers these findings can be a starting point to analyze and adapt curricula and teaching methods to promote more holistic thinking in disciplines such as engineering or computer science that allow students to have the competencies to face complex challenges with a variety of cognitive skills.

Table 3 reports the mean differences in the sub-competences of complex thinking with the group of careers related to engineering and computer science. It was found that there are statistically significant differences only in the systems thinking sub-competences, with the group of students in engineering careers presenting a higher percentage; no statistically significant differences were found in the other sub-competences. These findings are consistent with those reported by Vázquez-Parra et al. (2023) who refer in their study that engineering students reported higher means in the systems thinking sub-competences. This demonstrates the need to focus on strengthening systems thinking in the curriculum of computer science careers, an effective strategy could be interdisciplinary collaboration between different fields or areas of knowledge.

Table 4 shows the results of the mean differences in the sub-competences of complex thinking and the sex of the participants. Statistically significant differences were found in all the sub-competencies except for innovative thinking, in the sub-competencies in which significant differences were found, women presented higher means compared to men. These results are in line with what is reported in the literature in which women present higher means in the sub-competencies of complex thinking compared to men (Suárez-Brito et al., 2024). This implies that strategies for equal opportunities should be promoted so that both sexes can develop their potential in the sub-competences of complex thinking.

CONCLUSIONS

The study analyzed the perception of mastery of complex thinking sub-competencies in university students, finding that medical students perceive greater achievement in systemic, scientific, and innovative thinking, while data science and industrial engineering students stand out in critical thinking. Between engineering and computer science majors, significant differences were only observed in systems thinking, being higher in engineering. In addition, significant gender differences were found in all sub-competencies except innovative thinking, where women outperformed men, coinciding with previous studies. These results point to the need to adapt teaching methods to foster holistic thinking in areas such as engineering and to promote equal opportunities for both sexes in the development of complex competencies.

Limitations

The study represents a contribution to research on the use of serious games for the development of high-level cognitive skills such as complex thinking, however, it is important that the findings are taken with caution due to the limitations of this study, for example the sample size, although we sought to have a representative sample, some study careers have a smaller sample, so this could compromise the generalization of the findings, on the other hand, the measurement of self-reporting always involves a burden of social desirability, so this could represent at some point bias in the responses, it is suggested to include other formats for measuring the sub-competences of complex thinking. Finally, the cross-sectional design of the study does not allow us to establish causal relationships between the variables.

Theorical and Practical Implications

The findings of this study provide both theoretical and practical contributions to the understanding of how serious games can foster the development of complex thinking sub-competencies in higher education. Theoretically, the results reinforce the conceptual framework that positions complex thinking as a multidimensional and context-dependent meta-competence, shaped by disciplinary epistemologies, cognitive processes, and social interactions. The differences observed across academic programs and genders suggest that the development of systemic, critical, scientific, and innovative thinking is not homogeneous but contingent upon the learning environment and disciplinary culture in which students engage. This finding advances theoretical discussions on the interaction between digital learning environments and the cultivation of higher-order cognitive skills, emphasizing that serious games can function as catalysts for integrative reasoning and cognitive flexibility.

From a practical standpoint, the study offers relevant insights for curriculum design and instructional innovation. The higher perception of systemic and scientific thinking among medical students, for instance, indicates the effectiveness of pedagogical models that emphasize problem-solving and integrative decision-making. Conversely, the lower levels observed in some engineering and computer science programs highlight the need to embed serious games and interdisciplinary learning experiences that promote holistic reasoning and reflection. Integrating serious games that simulate real-world challenges may enhance students' ability to analyze systems, anticipate consequences, and apply creative solutions across contexts.

The gender-related differences identified also have significant educational implications. Women reported higher perceived achievement in most complex thinking sub-competencies, underscoring the importance of designing inclusive and equitable game-based learning environments. Educators and developers should ensure that game narratives, roles, and challenges encourage balanced participation and representation, promoting motivation and cognitive engagement for all learners regardless of gender. Overall, the findings support the integration of serious games as pedagogical tools for developing meta-competencies aligned with the demands of the 21st century–particularly adaptability, critical reasoning, and systems thinking. Their application in university programs may not only strengthen individual learning outcomes but also foster institutional innovation toward more inclusive, interdisciplinary, and sustainability-oriented education.

Future Research

Future studies should further examine how serious games contribute to the development of complex thinking sub-competencies through more rigorous and diverse research designs. Longitudinal and experimental studies are recommended to identify causal relationships between game-based learning and improvements in systemic, scientific, critical, and innovative thinking.

In addition, adopting mixed-method approaches that combine self-reported data with performance-based measures or qualitative insights would provide a more comprehensive understanding of how students internalize complex thinking during gameplay. Exploring the specific design features of serious games–such as feedback, collaboration, and narrative structure–could also help identify which elements most effectively foster higher-order cognitive skills. Finally, future research should consider cross-disciplinary and cross-cultural comparisons to determine how contextual factors, such as academic field or institutional culture, influence the impact of serious games on meta-competency development.

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Declaration of interest: The authors declared no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

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