JOURNAL OF INTERACTIVE MEDIA IN EDUCATION

Digital Environments of Education 4.0 and complex thinking: Communicative Literacy to close the digital gender gap

COLLECTION: OPENTEL

ARTICLE

CARLOS ENRIQUE GEORGE-REYES
IRIS CRISTINA PELÁEZ-SÁNCHEZ
LEONARDO DAVID GLASSERMAN-MORALES

*Author affiliations can be found in the back matter of this article

ubiquity press

ABSTRACT

The gender digital divide (GDD) is a social phenomenon that denies citizens access to technologies, the internet, and the services associated with Education 4.0. Reducing this gap requires communicative literacy, which allows scaling knowledge, skills, and attitudes to create forms of media expression to interact effectively in virtual environments. Education 4.0 is a modern approach to education that focuses on preparing students to thrive in a digital and technological world. Additionally, Education 4.0 is based on three pedagogical principles, including Cyber pedagogy, Heutagogy, and Peeragogy, which emphasize the use of technology, self-determined learning, and collaboration, respectively. A mixed study was conducted with the participation of 124 Mexican students of technical-professional education. The study's objective was to analyze how they scaled their communicative literacy and complex thinking through a formative experience based on the pedagogical framework of Education 4.0 in digital environments called metaverses to bridge the GDD in Mexico. Quantitative results show only significant differences in systemic thinking ($z = -2.113$, $p = 0.035 < 0.05$), where women had a slightly higher mean ($M = 25.36$) than men ($M = 25.11$). Qualitative results support the finding of women excelling in systemic thinking, as participants expressed comments related to systemic thinking (90%). This suggests that immersive digital environments can effectively enhance communicative literacy and complex thinking. Additionally, they can be spaces where both women and men achieve similar levels of digital literacy.

CORRESPONDING AUTHOR:
Carlos Enrique George-Reyes
Institute for the Future of Education, Tecnologico de Monterrey, MX
cgeorge@tec.mx

KEYWORDS:
communicative literacy; educational innovation; gender digital divide; complex thinking; immersive environments

TO CITE THIS ARTICLE:
George-Reyes, CE, Peláez-Sánchez, IC and Glasserman-Morales, LD. 2024. Digital Environments of Education 4.0 and complex thinking: Communicative Literacy to close the digital gender gap. *Journal of Interactive Media in Education*, 2024(1): 3, pp. 1–20. DOI: https://doi.org/10.5334/jime.833

INTRODUCTION

The digital divide is a social phenomenon that refers to the unequal access of citizens to digital technologies. This is accentuated by the inability of specific social sectors to acquire devices, products, and services related to information and communication technologies (ICT).

In addition, it is related to different levels of digital literacy and competencies to make intentional and appropriate use of computers, mobile phones, the internet, and its applications (Abu-Shanab & Al-Jamal 2015). The digital divide phenomenon has received much attention, both from international organizations (European Institute for Gender Equality 2019; International Telecommunication Union 2020; Huyer & Sikoska 2018; United Nations 2020; World Bank Group 2020) and from various researchers across the world (Alozie & Akpan-Obong 2017; Bala & Singhal 2018; Trivedi 2018; Singh & Pathak 2020), who agree that there is a balance between development and access to technologies, as well as their impact on society.

The World Bank Group (2020) has expressed significant challenges in closing the gender gap in digital skills. Therefore, there is a need to design digital literacy programs aimed at closing the digital gender gap and empowering women in the digital era (Kumari 2023). According to Mare (2021), women face various barriers in two main areas: a) their participation in STEM disciplines and b) the development of digital skills. These barriers are rooted in educational contexts as they generate inequalities in interaction with teachers, lack of access and exposure to technology, modesty in the expression of skills, and limited perceptions of resources (Xia 2023). Currently, women need help in acquiring digital skills compared to men. Therefore, they may require more training in this area to overcome these challenges, which may impede their ability to fully participate in the digital world and take advantage of technology-related opportunities (Chandra 2022).

This gap can appear in different forms, such as the ease of access to the internet, possession of technological devices, training in digital skills, participation in technology-related fields, and equal representation in the technology industry (Banerjee 2019). There are differences in digital literacy between men and women because women tend to face more significant obstacles to use technologies and consequently do not develop advanced digital skills (Choi et al. 2020). The gender digital divide (GDD) is due to gender discrimination in education and employment, the lack of female role models in the technology industry, and inequality in the distribution of resources and opportunities (Elena-Bucea et al. 2021). Lack of economic resources, gender stereotypes, and cultural norms also limit women's participation in technology-based educational and employment contexts (Jiang & Luh 2017).

The GDD continues to be a significant barrier to women's full participation in the digital world, impacting their economic development and contributions to society (Kuroda et al. 2019). One of the key issues related to the GDD is digital harassment, abuse, and violence in cyberspace, as it limits women's ability to have a voice and participate in decision-making. Furthermore, research highlights the implications of GDD in education, where there is a lack of gender-sensitive educational materials and girls' disinterest in IT-related professions (Alozie & Akpan-Obong 2017; Bikos, Stamovlasis & Tzifopoulos 2018; Zhang, Wang & Liu 2020). In education, the GDD is reflected in the false notion that computer labs are exclusive to men and in the lack of interest among girls and young women in IT-related professions (Pedraza 2021; Wong & Kemp 2018). Addressing these challenges is critical to bridging the GDD and fostering a more inclusive and equitable digital world for all (Gorlach & Agic 2019).

Bridging the GDD involves taking actions to ensure that women have equal and effective access to information and communication technology (Busch 2019) to ensure access to technology by removing economic barriers, providing digital literacy, promoting female role models in technology, strengthening access to Industry 4.0 spaces, and including a gender perspective in science and technology policy planning (Khamis & Vaughn 2018; Lee 2019; Qazi & Mujtaba 2019). It has been recognized that it is important to establish opportunities for gender equality in the digital realm. This can be achieved by encouraging women's involvement in developing digital technology, improving their digital knowledge and skills, promoting gender equality to content creators, and educating educators on gender equality (Xia 2023).

COMMUNICATIVE LITERACY AND GENDER DIGITAL DIVIDE: THE INTERVENTION OF EDUCATION 4.0

Digital literacy is the process of acquiring knowledge and developing the ability to adequately employ technologies in the digital world to facilitate the participation of workers, students, and citizen ecosystems increasingly mediated by the use of electronic systems (Martínez-Bravo, Sádaba-Chalezquer & Serrano-Puche 2021; Sandoval 2021), However, achieving this type of literacy is somewhat complex since it integrates a series of skills and attitudes essential to internalize the use of software, the internet and its applications to manage, analyze, synthesize, form and create new forms of media expression to communicate with others (Rosalina et al. 2021).

On the other hand, digital literacy can enhance the necessary skills for the professional development of young women (Mateus, Mangue & Ortiz-Repiso 2022) as it can stimulate creativity and innovation. In this context, various studies have explored the role of digital literacy in reducing the gender digital divide (Afiani 2018; Floyd 2020). Furthermore, research on promoting digital literacy within the framework of Education 4.0 has highlighted the numerous advantages these environments offer in the students' learning process (Purwanto, Fahmi & Cahyono 2023). However, there remains a vast field of research to analyze how this divide can be effectively reduced by using technologies associated with Education 4.0.

Building upon the above, Education 4.0 emerges as a concept stemming from the convergence of the Fourth Industrial Revolution (4IR) and education. This pedagogical approach represents a new way of teaching geared towards preparing future generations of professionals to thrive in a constantly evolving technological and globalized world (Ramírez-Montoya, McGreal & Obiageli-Agbu 2022). Education 4.0 focuses on problem-solving, integrating emerging technologies, and implementing innovative strategies to enhance pedagogical processes in higher education. Its primary objective is to equip students to apply physical and digital resources effectively in addressing present and future societal challenges (Miranda et al. 2021).

Education 4.0, as a pedagogical approach, primarily aims at preparing new generations to navigate a technologically evolving world. There is a strong emphasis on problem-solving, integrating emerging technologies, and implementing innovative strategies to develop essential skills in students (Matsumoto-Royo, Ramírez-Montoya & Conget 2021). Innovation, flexibility, and adaptability to change are deemed crucial aspects of societal development and education in Era 4.0 and within the realm of Education 4.0 (Kovaliuk & Kobets 2021).

According to Ramírez-Montoya et al. (2022), Education 4.0 combines three educational paradigms: Cyber pedagogy, Heutagogy, and Peeragogy. Cyber pedagogy focuses on the use of technology in learning (Rahma et al. 2021; Sumarsono 2020), as the internet and social media can facilitate socio-constructive learning in virtual and interactive environments (Tajudin et al. 2020). Heutagogy encourages self-determined learning through technological advances, promoting lifelong learning and student independence (Blaschke & Marín 2020). Finally, Peeragogy emphasizes collaborative learning and peer teaching to achieve educational goals and improve communicative skills (Corneli et al. 2015).

These pedagogical principles are crucial in reducing the GDD by fostering communication in digital media and developing competencies for virtual learning environments (Kuroda et al. 2019). Additionally, they strengthen motivation and confidence, which are essential for reducing the GDD in women (Rodríguez 2018; Martínez-Cantos & Castaño 2017). Likewise, they strengthen motivation and confidence, which are indispensable in women to reduce GDD (Rodríguez 2018; Martínez-Cantos & Castaño 2017). Figure 1 shows how the pedagogical framework of Education 4.0 can bridge the GDD.

The Fourth Industrial Revolution (4IR), or Industry 4.0, is converging with Education 4.0, leading to an evolution in educational paradigms and innovative pedagogical approaches to adapt to a constantly technologically changing society (Miranda et al. 2021). Industry 4.0 is characterized by integrating advanced technologies into production processes to enhance efficiency, flexibility, and personalization in product manufacturing (Rozo-García 2020). In general terms, Industry 4.0 is characterized by technologies that create competitive advantages by improving process efficiency and optimizing resources. Applications of Industry 4.0 offer economic, social,

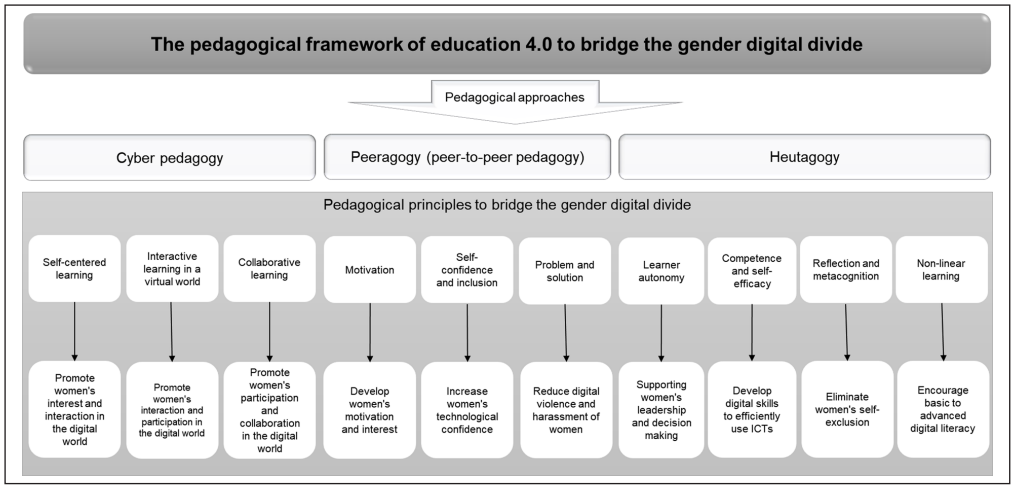

Figure 1 Bridging the gender digital divide through Education 4.0 pedagogical framework.

and environmental benefits as emerging technologies expand physical and digital experiences, and advances in artificial intelligence technology tools drive the productivity revolution (Brozzi et al. 2020; Nguyen 2023).

The evolution of education and vocational training is essential to meet the demands of the digital economy and Industry 4.0 (Li 2020). Education 4.0 is conceived as a response to changes in 21st-century society and technology, proposing innovative solutions to current educational challenges, such as implementing hybrid and online models and using digital tools to enhance learning and teaching (Sabando 2021). Emerging technologies like virtual reality (VR) are recognized to support Education 4.0 by improving pedagogical methods in higher education (Miranda et al. 2021).

Virtual reality (VR) creates immersive experiences by simulating digital environments, providing users with unique learning opportunities to explore situations and concepts safely and in a controlled manner (Ijiri 2022). This technology has been a significant trend in education over the past two decades, positively impacting student learning in various educational contexts (Chavez & Bayona 2018; Ijiri 2022; Li & Lan 2022; Radianti et al. 2020). In this context, Education 4.0 can offer virtual spaces that foster collaboration and communication to support participants' teaching and learning processes (Huang et al. 2019).

THE METAVERSE: IMMERSIVE ENVIRONMENT IN EDUCATION

The metaverse and its possibilities for achieving communicative literacy through access to virtual environments where users socialize, collaborate and learn through the development of immersive experiences has positioned itself as an alternative to strengthen student learning (Meta 2022), as well as to foster strategies such as problem-based learning, collaborative learning, role-playing, and gamification (Anacona, Millán & Gómez 2019). One of its main features is interactivity, corporeality through the design of an avatar, and persistence, understood as the functionality and evolution of the metaverse (Guo & Gao 2022).

The metaverse has evolved into three-dimensional shared virtual spaces (Hackl 2021), in which one can participate in alternate realities in which the virtually enhanced physical reality and the physically persistent virtual space converge (Radoff 2021). Kye et al. (2021) classify four types of metaverse: 1) augmented reality, 2) lifelogging, 3) mirror world, and 4) virtual reality, and suggest that the metaverse has the potential to consolidate as a new educational environment. Figure 2 shows an approach to the types of the metaverse, as well as the layers that integrate it.

In the educational context, the metaverse is associated with learning experiences that use a wide range of tools. These tools include devices such as HoloLens (Stromberg et al. 2021), virtual and augmented reality platforms that enable the construction of molecular models (Cortés, Dal Peraro & Abriata 2022), and gamification experiences designed to enhance motivation in the learning process (Park & Kim 2022). A notable example of an educational metaverse is the Virtual Campus of Tecnológico de Monterrey. In this environment, students can attend classes through personalized avatars as stated in the study by Glasserman-Morales, Ruíz-Ramírez and

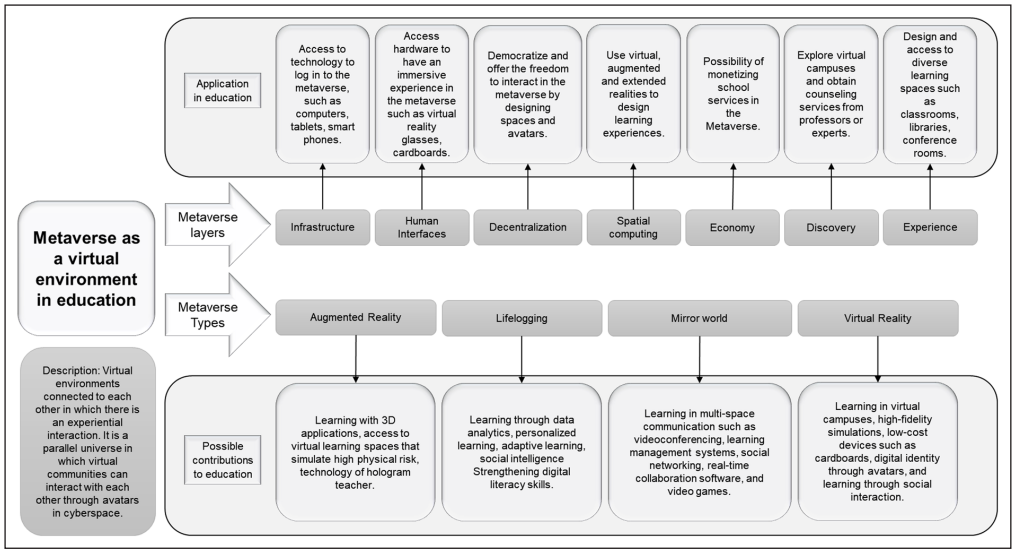

Figure 2 Metaverse composition.

Rocha (2022). This platform offers interactive and dynamic learning experiences to strengthen key competencies such as digital transformation, reasoning in complex contexts, social intelligence, and communicative literacy (Rocha et al. 2022).

From this context, the implementation of the metaverse as a learning strategy and for the development of communication skills opens up new opportunities for the inclusion of women in digital environments and, in this way, contributes to reducing the gender gap in the digital domain. However, it is important to highlight that incorporating emerging technologies and innovative strategies to enhance teaching can pose challenges for educators, who must acquire new skills and competencies, such as flexibility, to align their practices with Education 4.0 (Rienties et al. 2023).

On the other hand, the literature review on this topic has revealed that the development of 21st-century technologies and the evolution of Education 4.0 have widened the disparities in equitable technology use (Peláez-Sánchez et al. 2023). This phenomenon has led to an increase in the digital divide, limiting access, utilization, and appropriation of complex learning environments based on technologies such as augmented reality, virtual reality, data analytics, and blockchain, among others, for vulnerable groups, including women (Miranda et al. 2021). In this context, the urgency of reducing the digital divide becomes evident so that women can participate equitably in complex work and educational environments designed to address the growing demands of an ever-changing digital ecosystem (Kerras et al. 2020; Masdoki & Din 2021).

COMPLEX THINKING, THE METAVERSE, AND COMMUNICATIVE LITERACY

Education must respond to emerging challenges, including those in which the non-face-to-face modality is required as a means of training (Sepúlveda & Morrison 2020). Therefore, it is necessary to take advantage of the opportunities offered by technological trends to transform education. One of these technologies is the metaverse. However, they must be accompanied by complementary methodologies that serve as a connecting link.

One of these methodologies is complex thinking (CT), an enabler that helps interweave technologies with better academic decision-making (Vázquez, Cruz & Carlos 2022). This type of thinking comprises four subdimensions: scientific thinking (SCT), critical thinking (CT), systemic thinking (ST), and innovative thinking (IT) (Ramírez-Montoya et al. 2022) that allow the formation of cognitive skills in students and the development of communicative literacies needed to participate in the knowledge society and Education 4.0.

For instance, Ozdamar-Keskin et al. (2015) conceive communicative literacy as the ability to communicate effectively and work in collaboration using digital media from three dimensions: a) access to digital information (ADI), b) interpretation of digital information (IDI), and c) production and socialization of digital communication (PSDC). Figure 3 shows the components

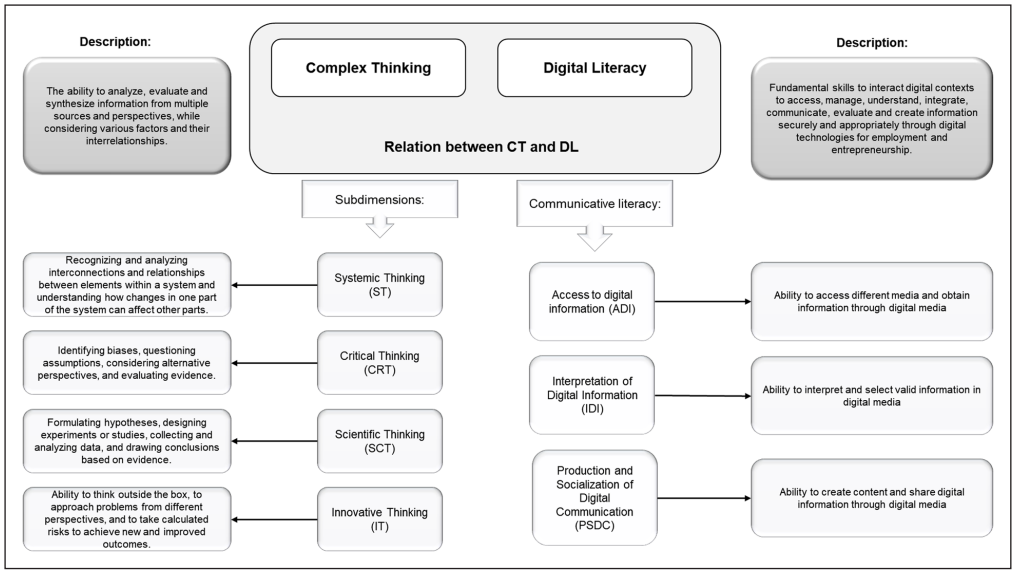

Figure 3 Components of complex thinking and communicative literacy.

of CT and how they are linked to communicative literacy (Abdul et al. 2020) and knowledge dissemination in active and hybrid learning ecologies (Vodovozov, Zoja & Petlenkov 2021; Wasilah, Insap & Sorour 2021).

Based on the literature review, it has been identified that there is still a vast field of research aimed at analyzing how this gap can be effectively reduced by utilizing technologies associated with Education 4.0. It was also found that developing communicative literacy and complex thinking has been recognized as a strategy to address the gender digital divide through Education 4.0. The research question that guided the study is: How does integrating communicative literacy and complex thinking, mediated by an educational experience based on the metaverse, contribute to reducing the perception of the gender digital divide in students from technical-professional schools?

METHOD

The research followed the mixed methods approach to connect and analyze the quantitative and qualitative data of the study in order to understand the phenomenon in depth (Tashakkori & Teddlie 2010). A mixed analysis from a QUAN + qual design was proposed to interpret the quantitative and qualitative data of the study collected through two techniques: a) a questionnaire for quantitative data collection and b) an interview to analyze the quantitative data (see Figure 4).

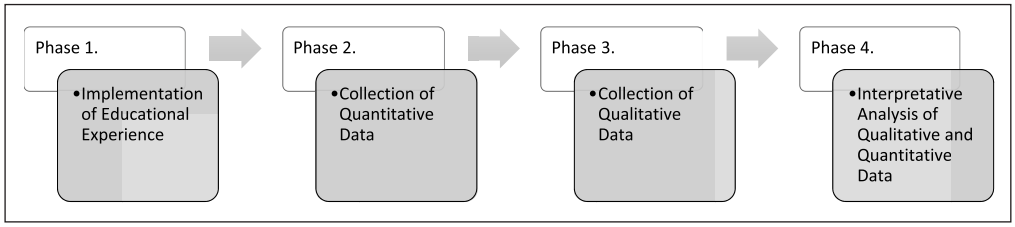

Figure 4 Design and phases of the study.

According to Sarango-Lapo, Mena and Ramírez-Montoya (2021), when it comes to Education 4.0, studying the introduction of new and advanced technological resources in higher education requires a mixed-method analysis. This approach provides a more complete and detailed understanding of the impact of these emerging technologies. Furthermore, Miranda et al. (2021) support the argument for conducting a mixed-methods study in the context of Education 4.0, as this methodology helps evaluate the positive impact on the development of competencies in participants through the quantitative and qualitative data collected in the study.

The main objective of this research was to design and implement a learning experience that enhances the communicative literacy of students, utilizing complex thinking and leveraging

the metaverse environment and the pedagogical framework of Education 4.0 to contribute to reducing the gender digital divide among students in technical and vocational schools in Mexico. The following guiding questions were established:

1. Are there significant differences between male and female students in a technical-professional high school in the development of communicative literacy and the complex thinking approach after the formative experience designed from the pedagogical framework of Education 4.0 to reduce the gender digital divide in Mexico?
2. Is there a correlation between the development of communicative literacy and the complex thinking approach in students of technical-professional high school after the formative experience designed from the pedagogical framework of Education 4.0 to reduce the gender digital divide in Mexico?
3. What is the perception of technical and vocational high school students regarding the development of communicative literacy from the perspective of complex thinking after the learning experience designed within the pedagogical framework of Education 4.0 to reduce the digital gender gap in Mexico?

A questionnaire adapted from the e-complexity questionnaire (Vázquez, Cruz & Carlos 2022) consisting of 24 items was employed to collect quantitative data. This questionnaire was administered after the immersive learning experience. The e-complexity questionnaire was chosen based on its interdisciplinary utility and close alignment with the pedagogical practices of Education 4.0 (Ramírez-Montoya et al. 2022). Furthermore, adapting the questionnaire ensured its validity and reliability within the specific context of this research.

Quantitative data analysis was divided into two stages: a) descriptive analysis and b) inferential analysis, aimed at verifying the existence of significant differences between women and men in three dimensions of digital literacy: a) access to digital information (ADI), b) interpretation of digital information (IDI), and c) production and socialization of digital communication (PSDC). The dimensions of complex thinking were also evaluated: scientific thinking (ST), critical thinking (CT), systemic thinking (SST), and innovative thinking (IT), in addition to seeking significant correlations through the Spearman coefficient. The software used to conduct these quantitative analyses was SPSS 26.

Regarding collecting qualitative data, semi-structured interviews were conducted with 20 participants who had experienced training in immersive environments. Including these interviews enriched the research by providing a deeper and qualitative understanding of the participants' experiences. The choice to interview 20 students was based on logistical and time considerations, recognizing that this balanced number allowed for capturing a diversity of opinions without overloading the available research resources. The qualitative data analysis was conducted by coding students' perceptions in immersive environments and their development of communicative literacy from the perspective of complex thinking using MAXQDA 2022 software.

In the final phase of the study, an interpretative analysis of the qualitative and quantitative data was conducted, and the dimensions of communicative literacy from the perspective of complex thinking that persisted in the previous two stages of the study were identified, following the approach proposed by Aguilar Gavira and Barroso Osuna (2015).

This educational research was conducted at a public institution in Mexico City with students from Technical-Professional Education (TPE), specifically in the morning shift's first, third, and fifth semesters. The sample was intentionally and conveniently selected, considering the availability and accessibility of the participants. It is crucial to emphasize that student participation was voluntary, and their informed consent, as well as that of their legal guardians, was obtained before including them in the study. It is important to note that the study was approved by the institution's management and Ethics Committee, supported by an official approval letter for conducting the study. The confidentiality of the collected information was ensured, preserving the anonymity of the participants.

THE INSTRUMENT

An adaptation of the e-complexity questionnaire (Vázquez, Cruz & Carlos 2022) was used as an instrument to investigate the scaling of communicative literacy from the complex thinking

approach. Table 1 shows the scale, which aims to measure the participant's perception of their level of communicative literacy in phase two of the study, where quantitative data collection was performed after having participated in the training experience designed within immersive environments from the pedagogical framework of Education 4.0 to promote the development of communicative literacy and reduce the gender digital divide.

DIMENSIONS OF COMMUNICATIVE LITERACY	SYSTEMIC THINKING (ST)	CRITICAL THINKING (CT)	SCIENTIFIC THINKING (SCT)	INNOVATIVE THINKING (IT)
Access to digital information (ADI)	I access different digital media to learn about the same information.	I know how to identify digital media that only covers some information.	I use information search strategies based on logical operators.	I recover and store information in digital media like Google Drive, Dropbox, Box, etc.
	I know how to use search strategies to find updated information (last week/month/year).	I protect the information stored in my digital devices with biometric passwords.	I filter the information using web tools.	I protect my personal digital information using secure passwords.
Interpretation of digital information (IDI)	To judge a piece of information, I contrast it with different sources.	I know how to estimate the credibility of information by differentiating between that which comes from reliable media and that which comes from unverified media.	I know how to use checking tools to validate the information from web pages and social networks.	I organize the information I recover using strategies such as shared folders, web bookmarks, local folders, social networks, etc.
	I create categories of digital information for later use in a task or project.	Before using the information, I evaluate whether it is fake news.	I reference an official page or a recognized author to interpret the information.	Based on trending information, I can generate an objective debate in my social networks.
Production and socialization of digital communication (PSDC)	I have shared information using various media such as web pages, social networks, videos, podcasts, etc.	I cite the sources from which I obtain information when producing and socializing digital content.	I use design strategies and techniques to elaborate digital information.	I have created content combining different media such as videos, audio, and images.
	The information I share respects the rules of digital citizenship, such as equity, ethics, objectivity, non-discrimination, etc.	Before sharing digital information, I identify the recipients.	I can identify licenses and copyrights before using the information to produce my content.	I have built a digital identity to socialize the digital information I share.

Table 1 Items of the adaptation of the e-complexity scale to measure communicative literacy.

We validated the instrument using Cronbach's alpha and McDonald's Omega coefficients. Table 2 shows the results where acceptable criteria are visualized since all dimensions' values are above 0.70 (Viladrich, Angulo-Brunet & Doval 2017). The dimensions that validated having high reliability, since the value of Cronbach's alpha coefficient were greater than 0.80, were: a) systemic thinking (ST) (.82) and b) innovative thinking (IT) (.749). Likewise, the dimensions were analyzed through McDonald's Omega coefficient, where each dimension was between .70 and .90. The reliability coefficients in both coefficients show acceptable to high values (see Table 2).

DIMENSIONS OF THE INSTRUMENT	CRONBACH'S ALPHA	MCDONALD'S OMEGA
Systemic Thinking	.825	.887
Critical Thinking	.757	.764
Scientific Thinking	.808	.812
Innovative Thinking	.749	.760

Table 2 Reliability coefficients of the dimensions.

INTERVENTION STRATEGY

A workshop called #unespaciovirtualentuescuela was implemented with four learning modules to develop communicative literacy from the approach of complex thinking through the use of an immersive 3D scenario in students of the technical-professional level. The purpose was to contribute to reducing the GDD of women. This training experience used a pedagogical approach based on the principles of Education 4.0 to support the reduction of the GDD. Table 3 shows the interconnection of the modules with the pedagogical framework of Education 4.0 and its orientation to reduce the GDD.

MODULES	OBJECTIVE	PEDAGOGICAL FRAMEWORK OF EDUCATION 4.0	PEDAGOGICAL PRINCIPLES	BRIDGING THE GENDER DIGITAL DIVIDE
Module 1. Introduction to the workshop	To familiarize participants with the use and management of their avatar in the Mozilla Hubs platform and resolve doubts in the first interaction in this virtual world.	Peeragogy (peer-to-peer pedagogy)	Motivation	Support the use of technology by identifying the motivations and interests of the GDD, which lacks technological inclination (Rodríguez, 2018).
			Confidence and inclusion	Support strengthens technological confidence in the GDD (Martínez-Cantos & Castaño 2017).
		Cyber pedagogy	Interactive learning in a virtual world	Encourage interaction in the digital world to foster equal participation among learners, as required in the GDD (Kuroda et al. 2019; de Andrés del Campo et al. 2020).
			Self-focused learning	Support interest and interaction in the digital world of young women to increase their technological self-efficacy (Gebhardt et al. 2019).
Module 2. Digital communication	To identify communication skills needed for life and their educational background.	Heutagogy	Learner autonomy	Fostering decision-making and leadership of female learners which are in short supply in GDD (Alozie & Akpan-Obong 2017).
		Cyber pedagogy	Collaborative learning	Encourage female learners' participation and collaboration in the digital world and social networks (Masanet, Pires & Gómez-Puertas 2021; Rai 2019).
Module 3. Social networks	To identify trending social networks and their uses as digital media for communication.	Heutagogy	Reflection and metacognition	Promote the elimination of self-exclusion of female students because of gender roles and stereotypes that occur in GDD (Alozie & Akpan-Obong 2017).
			Non-linear learning	Supporting the different levels of digital skills of learners recognized in the GDD (Krchová & Höesová 2021).
		Cyber pedagogy	Collaborative learning	Promote learners' participation and collaboration in social networks and the digital world (Masanet, Pires & Gómez-Puertas 2021; Rai 2019).
Module 4. My communicative skills developed in the workshop.	To create a video to describe the communicative skills that can be developed in a virtual room.	Heutagogy	Capability and self-efficiency	Develop digital skills necessary to effectively use digital technologies (Kuroda et al. 2019).
		Cyber pedagogy	Collaborative learning	Stimulate the collaboration of female students in the digital world and social networks (Masanet, Pires & Gómez-Puertas 2021; Rai 2019).

Table 3 Content of the modules developed based on the pedagogical framework of Education 4.0 and to bridge the gender digital divide.

The workshop modules were designed based on the methodology of complex thinking (CT) since this can be a valuable tool for education in the digital era. It is necessary to encourage its development in students to prepare them for future challenges. Thus, each module was articulated from the subdimensions of complex thinking: SCT, CT, ST, and IT, according to Ramírez-Montoya et al. (2022). The articulation of the workshop content also contemplated the dimension of communicative literacy that students would develop within immersive environments from a) ADI, b) IDI, and c) PSDC (Ozdamar et al. 2015) (see Table 4).

Table 4 Linking workshop modules to communicative literacy from the complex thinking approach.

Source: Own elaboration.

MODULE	COMMUNICATIVE LITERACY	COMPLEX THINKING	ENVIRONMENT
Module 1. Introduction to the workshop	Access to digital information (ADI)	Critical thinking (CT) & systemic thinking (ST)	Computer laboratory (face-to-face environment)
Module 2. Digital communication	Interpretation of digital information (IDI)	Critical thinking (CT) & systemic thinking (ST)	3D environments (Virtual Reality) Computer laboratory (face-to-face environment)
Module 3. Social networks	Interpretation of digital information (IDI)	Critical thinking (CT) & systemic thinking (ST)	3D environments (Virtual Reality) Computer laboratory (face-to-face environment)
Module 4. My communicative skills developed in the workshop	Production and socialization of digital communication (PSDC)	Systemic thinking (ST), scientific thinking (SCT) & innovative thinking (IT)	3D environments (Virtual Reality) Computer laboratory (face-to-face environment)

The workshop was face-to-face conducted in the computer laboratories of the educational institution. The immersive environments were developed through Mozilla Hubs, a social virtual reality platform developed by Mozilla, the organization behind the Firefox web browser. It is a tool that allows users to create and share virtual reality experiences online, accessed through a web browser or a compatible virtual reality device. This platform was selected to implement virtual rooms that can be created for free. Visual content was developed with the support of Synthesia. This video platform uses artificial intelligence technology to generate customized and automated videos in various languages and presentation styles. The immersive scenarios and videos designed for this educational intervention can be partially visualized in Figures 5 and 6.

Figure 5 3D immersive environment developed through Mozilla Hubs for #unespaciovirtualentuescuela workshop.

RESULTS

The study results are presented in a) quantitative and b) qualitative data. The quantitative analysis is presented in two stages: descriptive analysis and inferential analysis to answer the first two research questions of the study.

First, the population that had the formative experience within the immersive environments was 124 participants who were distributed into three groups: a) men (n = 73, 58.9%), b) women (n = 44, 35.5%), and non-binary students (n = 7, 5.6%). Although the population of the third group is less than 10%, it is considered relevant to show the results to avoid their exclusion.

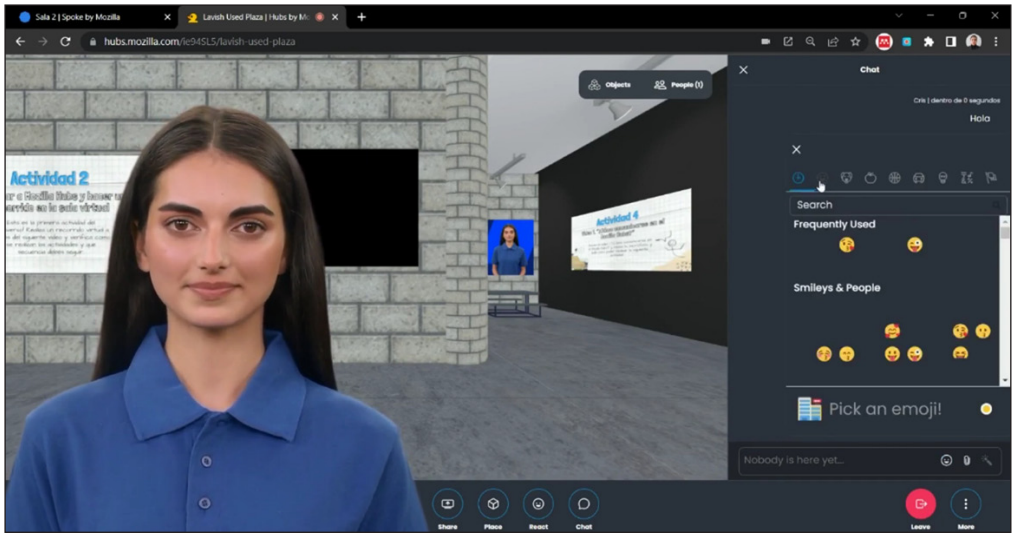

Figure 6 Video developed by Synthesia for #unespaciovirtualentuescuela workshop.

Most male students are 16 (n = 30, 36.7%) and 17 (n = 29, 39.7%). This figure is similar in female students, with 16 (n = 15, 34.1%) and 17 (n = 16, 36.4%). Binary students had participants from 15 to 16 years old (See Table 5).

Table 5 Study population by gender and age.

GENDER	AGE					TOTAL
	15	16	17	18	21	
Male	11	30	29	2	1	73
	15.1%	41.1%	39.7%	2.7%	1.4%	100.0%
Female	8	15	16	4	1	44
	18.2%	34.1%	36.4%	9.1%	2.3%	100.0%
Non-binary	3	3	1	0	0	7
	42.9%	42.9%	14.3%	0.0%	0.0%	100.0%
Total	22	48	46	6	2	124
	17.7%	38.7%	37.1%	4.8%	1.6%	100.0%

Descriptive statistics reveal that the mean scores for women are slightly higher in all three dimensions of communicative literacy. It is worth noting that in the production and socialization of digital communication (PSDC), women have a higher mean score (M = 25.32, SD = 4.376) compared to men (M = 23.89, SD = 4.659). On the other hand, the results indicate a similar perception in the AID dimension between men (M = 25.11, SD = 4.608) and women (M = 25.36, SD = 4.227), as well as in the IID dimension between men (M = 24.01, SD = 4.898) and women (M = 24.64, SD = 4.989) (See Table 6).

Table 6 Descriptive statistics of communicative literacy and complex thinking.

DIMENSIONS OF COMMUNICATIVE LITERACY AND COMPLEX THINKING	MALE		FEMALE		NON-BINARY	
	MEAN	SD	MEAN	SD	MEAN	SD
Access to digital information (ADI)	25.11	4.608	25.36	4.227	24.00	3.109
Interpretation of digital information (IDI)	24.01	4.898	24.64	4.989	24.43	3.259
Production and socialization of digital communication (PSDC)	23.89	4.659	25.32	4.376	24.43	2.149
Systemic thinking (ST)	18.22	3.568	19.45	3.454	17.71	2.563
Critical thinking (CT)	17.78	3.852	17.50	3.788	18.57	2.440
Scientific thinking (SCT)	18.59	3.378	19.00	3.355	18.43	1.988
Innovative thinking (IT)	18.42	3.480	19.36	3.349	18.14	3.024
N	73		44		7	

The results of the three groups were analyzed. The mean score for men in critical thinking (CT) (M = 17.78, SD = 3.852) was slightly higher than that of women (M = 17.50, SD = 18.57). However, in systemic thinking (ST), women had a slightly higher mean score (M = 19.45, SD = 3.454) than men (M = 18.22, SD = 3.568). The same pattern was observed in scientific thinking (ST) and innovative thinking (IT), where women had a slightly higher mean score (M = 19.00, SD = 3.355) than men (M = 18.59, SD = 4.659) in scientific thinking (ST) and (Women: M = 19.36, SD = 3.349) (Men: M = 18.42, SD = 3.480) in innovative thinking (IT). In summary, a slightly higher mean was identified for women in communicative literacy, specifically in access to digital information (ADI), and a similar mean for both groups in complex thinking, differing only in systemic thinking (ST), as previously mentioned.

To answer the first research question, "Are there significant differences between male and female students in a technical-professional high school in the development of communicative competence and the complex thinking approach after the training experience designed based on the pedagogical framework of Education 4.0 to reduce the gender digital divide in Mexico?" the Mann-Whitney U test for independent samples was conducted. The results validated that the differences are significant only in systemic thinking (ST) ($z = -2.113$, $p = 0.035 < 0.05$, Hedges' $g = 0.350$), where women had better results (M = 19.45, SD = 3.454) than men (M = 18.22, SD = 3.568). Furthermore, it was identified that the difference is moderate between the two groups in the systemic thinking dimension. Although the p-value in the other dimensions of complex thinking and communicative literacy dimensions is not significant ($p > 0.05$), the effect size in two dimensions of the study: a) PSDC (communicative literacy) and b) IT (complex thinking) is moderate (>0.20) (see Table 7).

Table 7 Mann-Whitney U test.
a. Grouping Variable: Gender.

TEST STATISTICS							
	COMMUNICATIVE LITERACY			COMPLEX THINKING			
	ADI	IDI	PSDC	ST	CT	SCT	IT
Mann-Whitney U	1521.500	1503.000	1331.000	1233.500	1459.500	1459.000	1416.500
Z	−0.478	−0.582	−1.557	−2.113	−0.830	−0.833	−1.073
Asymp. Sig. (2-tailed)	0.633	0.560	0.120	0.035	0.407	0.405	0.283
Hedges' *g*	0.056	0.127	0.316	0.350	0.073	0.121	0.275

To answer the second question of the study, "Is there a correlation between the development of communicative literacy and the complex thinking approach in students of technical-vocational high school after the formative experience designed from the pedagogical framework of education 4.0 to reduce the digital divide in Mexico?", the normality of the samples was validated through the *Kolmogórov-Smirnov* test. However, the data did not present a normal distribution ($p = 0.00 < .05$). Therefore, the correlation of the dimensions of communicative literacy: a) ADI, b) IDI, and c) PSDC and complex thinking was calculated: SCT, CT, ST, and IT through Spearman's Rho test. It is important to note that duplicate items were removed from each correlation to ensure an accurate measurement of the relationship between variables. The results reveal a high correlation between communicative literacy and complex thinking in all dimensions, as the correlation coefficients are close to 1. Furthermore, the correlation is significant in all dimensions ($p < 0.05$) (See Table 8).

DIMENSIONS		ST	SCT	CT	IT
ADI	Correlation Coefficient	.808	.763	.746	.783
	Sig. (2-tailed)	.000	.000	.000	.000
IDI	Correlation Coefficient	.730	.819	.765	.792
	Sig. (2-tailed)	.000	.000	.000	.000
PSDC	Correlation Coefficient	.776	.746	.775	.777
	Sig. (2-tailed)	.000	.000	.000	.000

Table 8 Level of correlation between the dimensions of communicative literacy and complex thinking.

The participants were asked about their experience in the virtual room, the communicative skills they believe can be developed in a virtual space like Mozilla, and how easy it was to communicate through the virtual room to answer the third question "What is the perception of technical and vocational high school students regarding the development of communicative literacy from the perspective of complex thinking after the learning experience designed within the pedagogical framework of Education 4.0 to reduce the digital gender gap in Mexico?". The data was analyzed using MAXQDA 2022, focusing on communicative literacy dimensions (ADI, IDI, PSDC) and complex thinking dimensions (SCT, CT, ST, IT), as illustrated in the Figure 7.

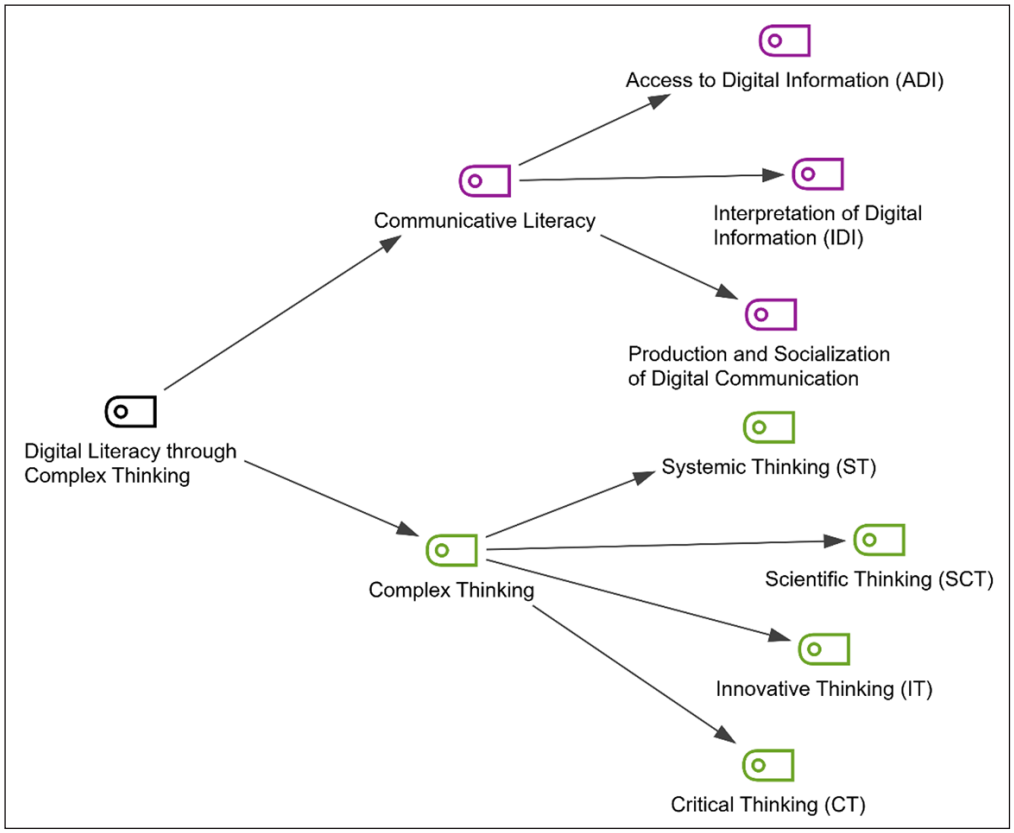

Figure 7 Coding analysis of communicative literacy and complex thinking approach.

The analysis results show that 90% of the participants expressed favorable comments regarding immersive environments, and their comments were primarily framed from a systemic thinking perspective. For instance, comments such as

> "Because there are several people in the same world, so you create your content by building your house, your avatar, things like that, and you interact with communities with people who are in that virtual world"; or

> "I think in this workshop we were able to interact through technologies because we are sharing ideas with the teachers and our peers, or we can also create content",

demonstrate a focus on systemic thinking and engagement in a complex digital environment. As Ramírez-Montoya et al. (2022) mentioned, systemic thinking involves the ability to see and understand how different parts of a system interact and how these interactions contribute to the comprehension of global phenomena and complex systems.

Furthermore, it was observed that the other three sub-dimensions were perceived at a similar level by the participants: scientific thinking (43%), critical thinking (52%), and innovative thinking (48%). Additionally, it was demonstrated that this workshop guided students in developing their communicative literacy across the three dimensions at different levels, as 76% of the students mentioned that this workshop helped them develop the dimension of production and socialization of digital communication. They considered that in this workshop, they could "Interact through technology and create content because I enjoyed making videos" or "In this workshop, I was able to create my video and share it with my friends; I saw that you can use these spaces at school as if you were playing". The second dimension of digital literacy

developed in immersive environments was access to digital information (43%), followed by the interpretation of digital information (43%) in third place (see Figure 8).

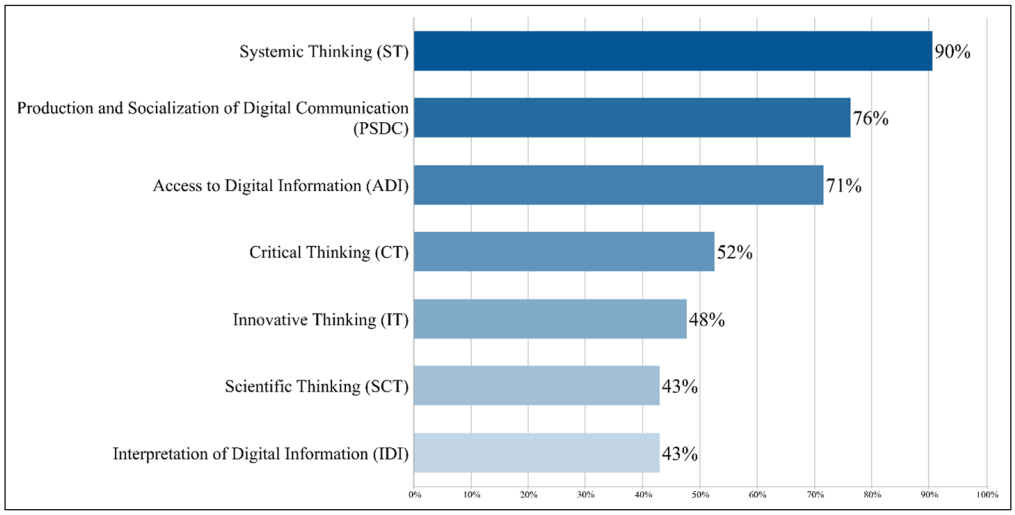

Figure 8 Frequency of communicative literacy and the complex thinking codes.

Qualitative data interpretation reveals that the three dimensions of communicative literacy were developed through immersive environments and the pedagogical framework of Education 4.0. Participants reported significant development in all three dimensions, especially in digital communication production and socialization during module 4. In contrast, quantitative data showed that access to digital information (ADI) was better in both groups, but women outperformed men in the production and socialization of digital communication (PSDC). Interestingly, both results are related. Moreover, the qualitative and quantitative results indicate that female students showed significant improvement in systemic thinking (ST) within immersive environments, with better results than male students. Finally, 90% of the participants reported that this formative experience supported the development of their systems thinking.

DISCUSSION

Immersive digital environments provide a unique opportunity to create innovative learning scenarios and promote communication and social participation, according to a study by Rocha et al. (2022). The study found that women scored higher in all dimensions of communicative literacy, including AID (+0.25), IDD (+0.63), and AID (+1.43). These findings contradict the negative and technophobic stereotypes often associated with women as regards the gender digital divide, as Rodríguez and Jiménez (2020) noted. Additionally, they support the Education 4.0 ideology, which advocates developing the digital skills necessary to succeed in the technological world (Matsumoto et al., 2021).

Education 4.0 unequivocally recognizes the integration of immersive environments as a pedagogical intervention strategy that offers unparalleled benefits for learning. Multiple studies, including the one conducted by Barráez-Herrera (2022), have demonstrated that these immersive environments facilitate student social and educational interactions. Additionally, these environments have the potential to bridge the digital divide and provide access to vulnerable groups, particularly women. The female participants in the study achieved commendable results in three sub-dimensions of complex thinking: ST (+1.23), SCT (+0.01), and IT (+0.94). These findings strongly support the use of adaptable and groundbreaking environments for developing collaborative learning activities based on the pedagogical principles of Education 4.0. Such environments allow students to learn independently and collaboratively in virtual and interactive settings, as emphasized by Tajudin et al. (2020).

In addition, the findings indicate that Education 4.0's teaching methods are a successful approach to reinforcing learning (Pacheco & Rosales 2022) and promoting student collaboration (Revuelta & Pedrera 2020). The educational activities in immersive environments encourage ongoing interaction and involvement among students. Developing simulations that closely resemble real-life situations in these environments can simplify intricate educational processes and result in significant learning achievements for participants (Ly, Saadé & Morin 2017).

This study suggests that using immersive environments can successfully promote competency development and social interaction in education, as proposed by Ayala Pezzutti et al. (2020). The findings indicate that incorporating metaverses into Education 4.0 can improve complex thinking skills for all students. Women perform better than men in systemic thinking, which is important for analyzing and understanding complex global systems and phenomena (Ramírez-Montoya et al. 2022).

CONCLUSIONS

The findings of this study indicate that Education 4.0 and immersive environments have a positive impact on the development of communicative literacy and complex thinking among students in technical-professional education. Moreover, these environments facilitate the digital inclusion of vulnerable groups, such as women. Despite the promising results, there are still some areas that require further investigation to fully comprehend the effects of immersive environments on student learning. Specifically, exploring the social and educational interactions between students in immersive environments and assessing the transferability of skills to real-life situations would be beneficial.

Additionally, investigating how educators can effectively incorporate immersive environments into various disciplines, as well as the impact of students' socioeconomic and cultural backgrounds on their skill development, would provide valuable insights. In conclusion, this study highlights the potential of Education 4.0 and immersive environments to improve education and promote digital inclusion. Further research is necessary to investigate the possibilities of these environments and to identify how they can be used to enhance student learning and skills effectively.

One of the limitations of the study is the delimitation of the population where the immersive experience was carried out, since it was selected at discretion, considering the availability of the subjects to participate in the study, however, this creates an opportunity to investigate further in other geographical contexts, and with this to enable comparisons to be made between age groups, gender, sociodemographic profiles, among others.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support of CILED.

FUNDING INFORMATION

The authors acknowledge the financial and technical support of Writing Lab, the Institute for the Future of Education, Tecnológico de Monterrey, Mexico, in producing this study, also the authors would like to thanks the financial support from Tecnologico de Monterrey through the "Challenge-Based Research Funding Program 2022". Project ID # I004 - IFE001 - C2-T3 – T.

COMPETING INTERESTS

We, the authors and reviewers of this research paper, declare that we have no competing interests concerning the research presented in this paper. We have no financial or personal relationships that could influence the research results or interpretation. We believe transparency and integrity are essential in scientific research and take our responsibility as researchers and reviewers seriously. Therefore, we have disclosed any potential competing interests and confirm that we have no conflicts related to this research. We hope that our findings contribute to advancing knowledge and that readers can evaluate our research objectively based on its scientific merits.

AUTHOR AFFILIATIONS

Carlos Enrique George-Reyes orcid.org/0000-0002-2529-9155
Institute for the Future of Education, MX

Iris Cristina Peláez-Sánchez orcid.org/0000-0002-3767-9497
Institute for the Future of Education, Tecnologico de Monterrey, MX

Leonardo David Glasserman-Morales orcid.org/0000-0001-7960-9537
Institute for the Future of Education, Tecnologico de Monterrey, MX

REFERENCES

Abdul, S, Selamat, A, Krejcar, A, Maresova, P and **Thanh, N.** 2020. Digital learning demand for future education 4.0—case studies at Malaysia education institutions. *Informatics*, 7(2): 13. DOI: https://doi.org/10.3390/informatics7020013

Abu-Shanab, E and **Al-Jamal, N.** 2015. Exploring the gender digital divide in Jordan. *Gender, Technology and Development*, 19(1): 91–113. DOI: https://doi.org/10.1177/0971852414563201

Afiani, I. 2018. Advancing women's digital skills and economic empowerment through girls in tech Indonesia: A case study. *SALASIKA: Indonesian Journal of Gender, Women, Child, and Social Inclusion's Studies*, 35(2): 21–32. DOI: https://doi.org/10.36625/sj.v1i1.39

Aguilar Gavira, S and **Barroso Osuna, JM.** 2015. La triangulación de datos como estrategia en investigación educativa. *Pixel-bit. Revista de Medios y Educación*, 47: 73–88. DOI: https://doi.org/10.12795/pixelbit.2015.i47.05

Alozie, NO and **Akpan-Obong, P.** 2017. The digital gender divide: Confronting obstacles to women's development in Africa. *Development Policy Review*, 35(2): 137–160. DOI: https://doi.org/10.1111/dpr.12204

Anacona, J, Millán, E and **Gómez, C.** 2019. Aplicación de los metaversos y la realidad virtual en la enseñanza. *Entre Ciencia e Ingeniería*, 13(25): 59–67. DOI: https://doi.org/10.31908/19098367.4015

Ayala Pezzutti, RJ, Laurente Cárdenas, CM, Escuza Mesías, CD, Núñez Lira, LA and **Díaz Dumont, JR.** 2020. Mundos virtuales y el aprendizaje inmersivo en educación superior. *Propósitos y representaciones*, 8(1). DOI: https://doi.org/10.20511/pyr2020.v8n1.430

Bala, S and **Singhal, P.** 2018. Gender digital divide in India: A case of inter-regional analysis of Uttar Pradesh. *Journal of Information, Communication and Ethics in Society*, 16(2): 173–192. DOI: https://doi.org/10.1108/JICES-07-2017-0046

Banerjee, P. 2019. Gender digital divide – examining the reality. *International Journal of Innovative Technology and Exploring Engineering*, 8(11 Special Issue): 214–219. DOI: https://doi.org/10.35940/ijitee.K1044.09811S19

Barráez-Herrera, DP. 2022. Metaversos en el contexto de la educación virtual. *Revista Tecnológica-Educativa Docentes 2.0*, 13(1): 11–19. DOI: https://doi.org/10.37843/rted.v13i1.300

Bikos, K, Stamovlasis, D and **Tzifopoulos, M.** 2018. Dimensions of digital divide and relationships with social factors: A study of Greek pre-service teachers. *Themes in eLearning*, 11(1): 23–34. http://earthlab.uoi.gr/tel/index.php/themeselearn/article/view/12.

Blaschke, LM and **Marín, VI.** 2020. Applications of heutagogy in the educational use of e-portfolios. *Revista de Educación a Distancia*, 20(64). DOI: https://doi.org/10.6018/red.407831

Brozzi, R, Forti, D, Rauch, E and **Matt, DT.** 2020. The advantages of Industry 4.0 applications for sustainability: Results from a sample of manufacturing companies. *Sustainability (Switzerland)*, 12(9). DOI: https://doi.org/10.3390/su12093647

Busch, L. 2019. The digital gender divide: Confronting obstacles to inclusion. *Journal of International Affairs*, 72(1): 9–27. https://jia.sipa.columbia.edu/digital-gender-divide-confronting-obstacles-inclusion.

Chandra, A. 2022. Bridging the digital gender divide: Prerequisite for women empowerment. In: Bala, S and Singhal, P (eds.), *Gender perspectives on Industry 4.0 and the impact of technology on mainstreaming female employment*. IGI Global. pp. 31–44. DOI: https://doi.org/10.4018/978-1-7998-8594-8.ch002

Chavez, B and **Bayona, S.** 2018. Virtual reality in the learning process. In Kacprzyk, J (ed.), *Advances in intelligent systems and computing*, 746: 1345–1356. Springer, Cham. DOI: https://doi.org/10.1007/978-3-319-77712-2_129

Choi, EY, Kim, Y, Chipalo, E, Lee, HY and **Meeks, S.** 2020. Does perceived ageism widen the digital divide? and does it vary by gender? *Gerontologist*, 60(7): 1213–1223. DOI: https://doi.org/10.1093/geront/gnaa066

Corneli, J, Jeffrey Danoff, C, Ricaurte, P and **Snow Macdonald, L.** 2015. Patterns of peeragogy. *PLoP '15: Proceedings of the 22nd Conference on Pattern Languages of Programs*, pp. 1–23.

Cortés, F, Dal Peraro, M and **Abriata, L.** 2022. Online tools to easily build virtual molecular models for display in augmented and virtual reality on the web. *Journal of Molecular Graphics and Modelling*, 114. DOI: https://doi.org/10.1016/j.jmgm.2022.108164

de Andrés del Campo, S, Collado Alonso, R and **García-Lomas Taboada, JI.** 2020. Brechas digitales de género. Una revisión del concepto. *Etic@net. Revista científica electrónica de Educación y Comunicación en la Sociedad del Conocimiento*, 20(1): 34–58. DOI: https://doi.org/10.30827/eticanet.v20i1.15521

Elena-Bucea, A, Cruz-Jesus, F, Oliveira, T and **Coelho, PS.** 2021. Assessing the role of age, education, gender and income on the digital divide: Evidence for the European Union. *Information Systems Frontiers*, 23(4): 1007–1021. DOI: https://doi.org/10.1007/s10796-020-10012-9

European Institute for Gender Equality. 2019. *Gender equality and the digital world*. https://eige.europa.eu/publications/gender-equality-and-digital-world.

Floyd, LA. 2020. Canada's CanCode Initiative and the gender gap in computer science education. *Proceedings of International Conference on Computational Thinking Education 2020*. https://lisaannefloyd.com/publications-and-media/. DOI: https://doi.org/10.1145/3328778.3372571

Gebhardt, E, Thomson, S, Ainley, J and **Hillman, K.** 2019. *Gender differences in computer and information literacy: An in-depth analysis of data from ICILS*. Springer https://link.springer.com/book/10.1007/978-3-030-26203-7. DOI: https://doi.org/10.1007/978-3-030-26203-7_1

Glasserman-Morales, LD, Ruíz-Ramírez, JA and **Rocha, FJ.** 2022. Transformando la educación superior mediante WebVR: Un caso de estudio. *IEEE Revista Iberoamericana de Tecnologías del Aprendizaje*, 17(3): 230–34. DOI: https://doi.org/10.1109/RITA.2022.3191257

Gorlach, K and **Agic, D.** 2019. Gender digital divide in Europe. *International Journal of Gender, Science, and Technology*, 11(1). DOI: https://doi.org/78-92.10.30845/ijbht.v10n4p2

Guo, H and **Gao, W.** 2022. Metaverse-powered experiential situational English-teaching design: An emotion-based analysis method. *Frontiers in Psychology*, 13. DOI: https://doi.org/10.3389/fpsyg.2022.859159

Hackl, C. 2 May 2021. Defining the metaverse today. *Forbes* [online]. Available at https://www.forbes.com/sites/cathyhackl/2021/05/02/defining-the-metaverse-today/.

Huang, YC, Backman, SJ, Backman, KF, McGuire, FA and **Moore, DW.** 2019. An investigation of motivation and experience in virtual learning environments: A self-determination theory. *Education and Information Technologies*, 24(1): 591–611. DOI: https://doi.org/10.1007/s10639-018-9784-5

Huyer, S and **Sikoska, T.** 2018. *Gender and the digital revolution*. United Nations Educational, Scientific and Cultural Organization. https://unesdoc.unesco.org/ark:/48223/pf0000260153.

Ijiri, A. 2022. Immersive learning in virtual reality. *International Conference on The Future of Education*. https://conference.pixel-online.net/files/foe/ed0012/FP/7778-ICT5506-FP-FOE12.pdf.

International Telecommunication Union. 2020. Measuring digital development: Facts and figures 2020. https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2020.pdf.

Jiang, W and **Luh, Y.** 2017. Gender digital divide in a patriarchal society: What can we learn from Blinder–Oaxaca decomposition? *Quality and Quantity*, 51(6): 2555–2576. DOI: https://doi.org/10.1007/s11135-016-0409-z

Kerras, H, Sánchez-Navarro, JL, López-Becerra, EI and **de-Miguel Gomez, MD.** 2020. The impact of the gender digital divide on sustainable development: Comparative analysis between the European Union and the Maghreb. *Sustainability*, 12(8): 3347. DOI: https://doi.org/10.3390/su12083347

Khamis, S and **Vaughn, K.** 2018. Gender and digital divides in the Arab region: Foundations for a research agenda. *Information, Communication & Society*, 21(9): 1267–1283. https://www.tandfonline.com/doi/full/10.1080/1369118X.2017.1335854.

Kovaliuk, T and **Kobets, N.** 2021. The concept of an innovative educational ecosystem of Ukraine in the context of the approach "Education 4.0 for Industry 4.0". *CEUR Workshop Proceedings*.

Krchová, H and **Höesová, KŠ.** 2021. Selected determinants of digital transformation and their influence on the number of women in the ICT sector. *Entrepreneurship and Sustainability Issues*, 8(4): 524–535. DOI: https://doi.org/10.9770/jesi.2021.8.4(31)

Kumari, M. 2023. Examining the impact of ICT and education in empowering women for self-reliance: A comprehensive review. *International Journal of Applied Social Science*, 10(5&6): 407–411. DOI: https://doi.org/10.36537/IJASS/10.5&6/407-411

Kuroda, R, Lopez, M, Sasaki, J and **Settecase, M.** 2019. *The digital gender gap*. (Policy Brief, W20 Japan 2019) EY. GSM Association.

Kye, B, Han, N, Kim, E, Park, Y and **Jo, S.** 2021. Educational applications of metaverse: Possibilities and limitations. *Journal of Educational Evaluation for Health Professions*, 18. DOI: https://doi.org/10.3352/jeehp.2021.18.32

Lee, K. 2019. Understanding the gender digital divide in developing countries: A literature review. *Telematics and Informatics*, 36: 13–23. https://www.sciencedirect.com/science/article/pii/S0736585318301509.

Li, L. 2020. Education supply chain in the era of Industry 4.0. *Systems Research and Behavioral Science*, 37(4): 579–592. DOI: https://doi.org/10.1002/sres.2702

Li, P and **Lan, YJ.** 2022. Digital Language Learning (DLL): Insights from behavior, cognition, and the brain. *Bilingualism*, 25(3): 361–378. DOI: https://doi.org/10.1017/S1366728921000353

Ly, S, Saadé, R and **Morin, D.** 2017. Immersive learning: Using a web-based learning tool in a Phd course to enhance the learning experience. *Journal of Information Technology Education Research*, 16: 227–246. DOI: https://doi.org/10.28945/3732

Mare, A. 2021. Addressing digital and innovation gender divide: Perspectives from Zimbabwe. *Entrepreneurship, technology commercialisation, and innovation policy in Africa*, 33–54. DOI: https://doi.org/10.1007/978-3-030-58240-1_3

Martínez-Bravo, MC, Sádaba-Chalezquer, C and **Serrano-Puche, J.** 2021. Meta-marco de la alfabetización digital: Análisis comparado de marcos de competencias del Siglo XXI. *Revista Latina de Comunicacion Social*, 2021(79): 76–110. DOI: https://doi.org/10.4185/RLCS-2021-1508

Martínez-Cantos, JL and **Castaño, C.** 2017. La brecha digital de género y la escasez de mujeres en las profesiones TIC. *Panorama Social*, 25: 49–65. https://www.funcas.es/wp-content/uploads/Migracion/Articulos/FUNCAS_PS/025art05.pdf.

Masanet, M-J, Pires, F and **Gómez-Puertas, L.** 2021. Riesgos de la brecha digital de género entre los y las adolescentes. *Profesional de la Informacion*, 30(1): 1–15. DOI: https://doi.org/10.3145/epi.2021.ene.12

Masdoki, M and **Din, R.** 2021. Teaching 4.0 competency in higher learning institutions: A systematic mapping review. *International Journal of Learning, Teaching and Educational Research*, 20(10). DOI: https://doi.org/10.26803/ijlter.20.10.12

Mateus, DL, Mangue, MV and **Ortiz-Repiso, V.** 2022. La alfabetización digital de mujeres hacia la inclusión digital y el cumplimento de la agenda 2030: Una comparación entre las políticas públicas de inclusión digital en Mozambique y España. *Perspectivas em Ciência da Informação*, 27(2): 320–354. DOI: https://doi.org/10.1590/1981-5344/40004

Matsumoto-Royo, K, Ramírez-Montoya, MS and **Conget, P.** 2021. Opportunities to develop lifelong learning tendencies in practice-based teacher education: Getting ready for education 4.0. *Future Internet*, 13(11). DOI: https://doi.org/10.3390/fi13110292

Meta. 2022. *Meta immersive learning. Create, learn and grow in the metaverse*. https://about.facebook.com/immersive-learning/.

Miranda, J, Navarrete, C, Noguez, J, Molina-Espinosa, JM, Ramírez-Montoya, MS, Navarro-Tuch, SA, Bustamante-Bello, MR, Rosas-Fernández, JB and **Molina, A.** 2021. The core components of education 4.0 in higher education: Three case studies in engineering education. *Computers and Electrical Engineering*, 93. DOI: https://doi.org/10.1016/j.compeleceng.2021.107278

Nguyen, T. 2023. The 2023 Gartner Emerging Technologies and Trends Impact Radar shows product leaders where to capitalize on market opportunities. Gartner Inc. https://www.gartner.com/en/articles/4-emerging-technologies-you-need-to-know-about?utm_medium=socialyutm_source=linkedinyutm_campaign=SM_GB_YOY_GTR_SOC_SF1_SM-SWGyutm_content=ysf263823822=1.

Ozdamar-Keskin, N, Zeynep Ozata, F, Banar, K and **Royle, K.** 2015. Examining digital literacy competences and learning habits of open and distance learners. *Contemporary Educational Technology*, 6(1): 74–90. https://files.eric.ed.gov/fulltext/EJ1105611.pdf. DOI: https://doi.org/10.30935/cedtech/6140

Pacheco, X and **Rosales, E.** 2022. TIC en la educación en contextos de disrupción tecnológica. *Reciamuc*, 6(1): 139–148. https://reciamuc.com/index.php/RECIAMUC/article/view/770/1153. DOI: https://doi.org/10.26820/reciamuc/6.(1).enero.2022.139-148

Park, S and **Kim, S.** 2022. Identifying world types to deliver gameful experiences for sustainable learning in the metaverse. *Sustainability (Switzerland)*, 14(3). DOI: https://doi.org/10.3390/su14031361

Pedraza, CI. 2021. La brecha digital de género como vértice de las desigualdades de las mujeres en el contexto de la pandemia por Covid-19. *LOGOS Revista de Filosofía*, 136(136): 9–22. DOI: https://doi.org/10.26457/lrf.v136i136.2873

Peláez-Sánchez, IC, George Reyes, CE and **Glasserman-Morales, LD.** 2023. Gender digital divide in education 4.0: A systematic literature review of factors and strategies for inclusion. *Future in Educational Research*. DOI: https://doi.org/10.1002/fer3.16

Purwanto, A, Fahmi, K and **Cahyono, Y.** 2023. The benefits of using social media in the learning process of students in the digital literacy era and the education 4.0 era. *Journal of Information Systems and Management (JISMA)*, 2(2): 1–7. DOI: https://doi.org/10.4444/jisma.v2i2.296

Qazi, A and **Mujtaba, G.** 2019. Digital gender divide: A comparison of women's online behavior in Pakistan and the UK. *Journal of Global Information Technology Management*, 22(2): 70–91. https://www.tandfonline.com/doi/abs/10.1080/1097198X.2019.1577221

Radianti, J, Majchrzak, TA, Fromm, J and **Wohlgenannt, I.** 2020. A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers and Education*, 147. DOI: https://doi.org/10.1016/j.compedu.2019.103778

Radoff, J. 7 April 2021. The metaverse value chain. *Medium* [online]. https://medium.com/building-the-metaverse/the-metaverse-value-chain-afcf9e09e3a7.

Rahma, RA, Sucipto, S, Affriyenni, Y and **Widyaswari, M.** 2021. Cybergogy as a digital media to facilitate the learning style of millennial college students. *World Journal on Educational Technology: Current Issues*, 13(2): 223–235. DOI: https://doi.org/10.18844/wjet.v13i2.5691

Rai, A. 2019. Digital divide: How do women in South Asia respond? *International Journal of Digital Literacy and Digital Competence (IJDLC)*, 10(1): 1–14. DOI: https://doi.org/10.4018/IJDLDC.2019010101

Ramírez-Montoya, MS, Castillo-Martínez, IM, Sanabria-ZJ and **Miranda, J.** 2022. Complex thinking in the framework of Education 4.0 and Open Innovation—A systematic literature review. *Journal of Open Innovation: Technology, Market, and Complexity*, 8(1): 4. DOI: https://doi.org/10.3390/joitmc8010004

Ramírez-Montoya, MS, McGreal, R and **Obiageli-Agbu, JF.** 2022. Horizontes digitales complejos en el futuro de la educación 4.0: Luces desde las recomendaciones de UNESCO. *RIED-Revista Iberoamericana de Educacion a Distancia*, 25(2): 09–21. DOI: https://doi.org/10.5944/ried.25.2.33843

Revuelta, FI and **Pedrera, MI.** 2020. *Retos y evidencias en la investigación con videojuegos en educación*. Ediciones Octaedro, S. L.

Rienties, B, Ferguson, R, Gonda, D, Hajdin, G, Herodotou, C, Iniesto, F, Llorens Garcia, A, Muccini, H, Sargent, J, Virkus, S and **Isidori, MV.** 2023. Education 4.0 in higher education and computer science: A systematic review. *Computer Applications in Engineering Education* (Early Access). DOI: https://doi.org/10.1002/cae.22643

Rocha Estrada, F, Ruiz-Ramirez, A, George-Reyes, C and **Glasserman-Morales, L.** 2022. Evaluation of a virtual campus adapted to WebVR Spaces: Assessments of teachers and students. *Frontiers in Education*, 7: 918125. DOI: https://doi.org/10.3389/feduc.2022.918125

Rodríguez, MR and **Jiménez, R.** 2020. Inclusión digital de las mujeres en las políticas españolas de la sociedad de la información. *Athenea Digital. Revista de Pensamiento e Investigación Social*, 20(2): 1–26. https://dialnet.unirioja.es/ejemplar/556613.

Rodríguez Portes, DL. 2018. Brecha digital de género entre estudiantes de la pucese. *Rev. Hallazgos21*, 3(3). https://revistas.pucese.edu.ec/hallazgos21/article/view/311/216.

Rosalina, D, Yuliari, K, Setianingsih, D and **Rizqi, MZ.** 2021. Factors influencing the digital literacy competency of college students in the Industrial Revolution Era 4.0. *IJEBA: International Journal of Economics, Business and Applications*, 6(2): 1–16. DOI: https://doi.org/10.31258/ijeba.6.2.81-92

Rozo-García, F. 2020. Revisión de las tecnologías presentes en la industria 4.0. *Revista UIS Ingenierías*, 19(2): 177–191. DOI: https://doi.org/10.18273/revuin.v19n2-2020019

Sabando, AV. 2021. Educación 4.0 y su impacto en el sistema educativo durante la pandemia y post pandemia Covid 19 en el Ecuador. *Sinergias educativas*, 7(1). http://portal.amelica.org/ameli/jatsRepo/382/3822817007/index.html.

Sandoval, CH. 2021. Alfabetización digital como puente de exclusión social poscovid-19. *Revista Tecnológica-Educativa Docentes 2.0*, 11(1): 120–129. DOI: https://doi.org/10.37843/rted.v11i1.200

Sarango-Lapo, CP, Mena, J and **Ramírez-Montoya, MS.** 2021. Evidence-based educational innovation model linked to digital information competence in the framework of education 4.0. *Sustainability*, 13(18): 10034. DOI: https://doi.org/10.3390/su131810034

Sepúlveda, P and **Morrison, A.** 2020. Online teaching placement during the COVID-19 pandemic in Chile: Challenges and opportunities. *European Journal of Teacher Education*, 43(4): 587–607. DOI: https://doi.org/10.1080/02619768.2020.1820981

Singh, A and **Pathak, RK.** 2020. Gender digital divide in India: A study of socioeconomic factors. *International Journal of Information Management*, 52: 102049. DOI: https://doi.org/10.1016/j.ijinfomgt.2019.07.002

Stromberg, Z, Phelps, C, Smith, J and **Moro, C.** 2021. Teaching with disruptive technology: The use of augmented, virtual, and mixed reality (HoloLens) for disease education. In: Rea, PM (ed.), *Biomedical Visualisation. Advances in Experimental Medicine and Biology, vol 1317*. Cham: Springer. DOI: https://doi.org/10.1007/978-3-030-61125-5_8

Sumarsono, S. 2020. The paradigms of heutagogy and cybergogy in the transdisciplinary perspective. *Jurnal Pendidikan dan Pengajaran*, 52(3): 172–182. DOI: https://doi.org/10.23887/jpp.v52i3.22882

Tajudin, MN, Suhaimi, NA, Adnan, M and **Puteh, M.** 2020. Promoting transformative mathematical learning through heutagogy, paragogy, and cybergogy approaches. *Palarch's Journal Of Archaeology Of Egypt/Egyptology*, 17(10): 481–497. DOI: https://doi.org/10.48080/jae.v17i10.4374

Tashakkori, A and **Teddlie, C.** 2010. Putting the human back in "human research methodology": The researcher in mixed methods research. *Journal of mixed methods research*, 4(4): 271–277. DOI: https://doi.org/10.1177/1558689810382532

Trivedi, A. 2018. Digital divide and gender: A study of rural India. *International Journal of Gender, Science, and Technology*, 10(1): 44–61. http://genderandset.open.ac.uk/index.php/genderandset/article/view/535.

United Nations. 2020. Policy brief: The impact of COVID-19 on women. https://www.un.org/sites/un2.un.org/files/policy_brief_on_covid_impact_on_women_9_apr_2020_updated.pdf.

Vázquez, J, Cruz, M and **Carlos, M.** 2022. Social entrepreneurship and complex thinking: A bibliometric study. *Sustainability*, 14: 13187. DOI: https://doi.org/10.3390/su142013187

Viladrich, C, Angulo-Brunet, A and **Doval, E.** 2017. A journey around alpha and omega to estimate internal consistency reliability. *Annals of Psychology*, 33(3): 755–782. DOI: https://doi.org/10.6018/analesps.33.3.268401

Vodovozov, V, Zoja, R and **Petlenkov, E.** 2021. Challenges of active learning in view of integrated engineering education. *Education Sciences*, 11(2): 1–14. DOI: https://doi.org/10.3390/educsci11020043

Wasilah, L, Insap, P and **Sorour, S.** 2021. Study on the influencing factors of the flexibility of university IT management in Education 4.0. *International Journal of Innovation and Learning*, 30(2): 132–153. DOI: https://doi.org/10.1504/IJIL.2021.117219

Wong, B and **Kemp, PEJ.** 2018. Technical boys and creative girls: The career aspirations of digitally skilled youths. *Cambridge Journal of Education*, 48(3): 301–316. DOI: https://doi.org/10.1080/0305764X.2017.1325443

World Bank Group. 2020. *Women, business and the law 2020*. https://openknowledge.worldbank.org/handle/10986/33738.

Xia, R. 2023. Examining the optimal option for gender equality education in the digital era. *Journal of Education, Humanities and Social Sciences*, 12: 217–223. DOI: https://doi.org/10.54097/ehss.v12i.7639

Zhang, P, Wang, L and **Liu, C.** 2020. The empowerment of singleton daughters: Exploring the gender digital divide among Chinese college students. *Information Technology and People*, 34(5): 1401–1418. DOI: https://doi.org/10.1108/ITP-07-2019-0350

TO CITE THIS ARTICLE:
George-Reyes, CE, Peláez-Sánchez, IC and Glasserman-Morales, LD. 2024. Digital Environments of Education 4.0 and complex thinking: Communicative Literacy to close the digital gender gap. *Journal of Interactive Media in Education*, 2024(1): 3, pp. 1–20. DOI: https://doi.org/10.5334/jime.833

Submitted: 25 April 2023
Accepted: 29 November 2023
Published: 15 February 2024

Journal of Interactive Media in Education is a peer-reviewed open access journal published by Ubiquity Press.