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Educational digital transformation: New technological challenges for competence development

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Educational digital transformation: New technological challenges for competence development

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Editorial: Educational digital transformation: new technological challenges for competence development

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Editorial on the Research Topic
Educational digital transformation: new technological challenges for competence development

In recent years, the rapid advancement of technology has driven a paradigm shift in education, leading to the digital transformation of learning environments (Cabero-Almenara et al., 2022). Educational institutions worldwide have embraced this transformation, leveraging digital tools and platforms to enhance teaching and learning processes (Marimon-Martí et al., 2022; Vásquez Peñafiel et al., 2023). This editorial introduces contributions to the Research Topic "*Educational digital transformation: new technological challenges for competence development*", which seeks to improve training policies and practices to foster educational development.

The contributions presented in this editorial delve into various aspects of digital transformation in education. From exploring students' experiences with distance education and videoconferencing fatigue to examining the impact of video games on teacher training and the teaching of programming and computational thinking, the studies offer valuable insights into the challenges and opportunities presented by the digital age.

The research contributions are interconnected and provide a comprehensive overview of the challenges and possibilities in educational digital transformation. Firstly, "*A qualitative exploration of university students' perspectives on distance education in Jordan*" (Al-Tammemi et al.) highlights the challenges faced during the transition to online learning, emphasizing the role of academic institutions and decision-makers in shaping students' educational experiences.

The issue of videoconferencing fatigue and its impact on online student engagement is addressed in "*Videoconferencing fatigue and online student engagement among Filipino senior high school students*" (Dacillo et al.). The study reveals how excessive videoconferencing can lead to reduced energy and hinder academic performance. This highlights the need for well-designed online learning experiences that promote active engagement and mitigate the negative effects of videoconferencing fatigue.

"*Psychometric study of a scale on the use of video games for the initial training of teachers*" (González et al.) presents the potential of video games as tools for teacher training. The

study's findings demonstrate that incorporating video games into teacher education can be effective and align with pedagogical objectives.

The global perspective on the teaching of programming and computational thinking is explored in "*Review on the teaching of programming and computational thinking in the world*" (Belmar a). While some countries have embraced these subjects in their curricula, the study underscores the disparities in implementation worldwide.

"*Medical education during the coronavirus disease pandemic and students' mental health: a one-year follow-up*" (Bolatov et al.) examines the impact of the COVID-19 pandemic on medical education and the mental health of students. The study's findings have implications for organizing and improving the quality of medical education during crises.

Comparative analysis of students' digital competencies in Belgium and Romania is presented in "*Student's digital competences in Belgium and Romania: a comparative analysis*" (Vodă et al.). The study highlights differences in digital skillsets between students from different regions, providing valuable insights for educational policy and curriculum development.

"*Views of secondary education teachers on the use of mixed reality*" (Marín-Díaz and Sampedro-Requena) explores the potential of mixed reality technology to enhance the learning process for secondary school students. The study emphasizes the importance of integrating emerging technologies in education to cater to diverse learning needs.

The impact of the COVID-19-induced shift to online assessments is investigated in "*Face-to-face versus online-based lectures: A COVID-19 induced study on assessments*" (Fisher et al.). The study reveals the differences in student performance between traditional and online assessments, shedding light on the effectiveness of remote evaluation methods.

"*The role of talent development on business performance in Islamic rural banks*" (Nurfadilah et al.) examines the relationship between digital readiness, strategic flexibility, innovativeness, and business performance in Islamic rural banks. The study emphasizes the importance of talent development in achieving organizational goals in the digital era.

"*Digital transformation in times of crisis: challenges, attitudes, opportunities, and lessons learned from students' and faculty members' perspectives*" (Aljanazrah et al.) employs the Unified Theory of Acceptance and Use of Technology (UTAUT) to investigate the impact of digital transformation during crises. The study highlights the challenges faced by stakeholders and provides valuable insights for future crisis preparedness.

"*Modeling the relationship between digital nativity and Smartphone usage in learning English as a foreign language contexts*" (Hui et al.) explores the relationship between digital nativity and smartphone usage in language learning contexts. The study emphasizes the importance of understanding learners' digital preferences to enhance language education.

"*Digital competencies of Peruvian teachers in basic education*" (Hurtado-Mazeyra et al.) assesses the digital competencies of teachers in Peru, aligning with the European Framework of Digital Competence. The findings underscore the importance of teacher training to effectively integrate digital tools into the classroom.

"*Knowledge in digital environments: a systematic review of literature*" (Platonova et al.) offers a comprehensive review of research on knowledge creation and sharing in digital environments. The study identifies various theoretical approaches and models used to understand knowledge processes in the digital age.

"*Enhancing cognitive combat readiness: gamers' Behaviors concentrating on convergent learning style, tacit-latent, and kinetic-active knowledge acquisitions*" (Sumiyana et al.) explores the cognitive benefits of gaming in combat readiness. The study underscores the potential of gamified learning to develop critical cognitive skills in military contexts.

"*Student evaluation of teacher digital skills at Granada University*" (Alonso-García et al.) examines students' perceptions of their teachers' digital skills. The study emphasizes the importance of educators' technological proficiency in providing effective digital learning experiences.

"*The impact of the digital divide on synchronous online teaching in Kazakhstan during COVID-19 school closures*" (Amirova et al.) investigates how the digital divide affected synchronous online teaching in Kazakhstan during the COVID-19 pandemic. The study highlights the need for equitable access to technology and digital skills training to ensure inclusive education.

"*Teaching computer programming: impact of Brown and Wilson's didactical principles*" (Belmar b) focuses on the application of didactics to computer programming education. The study underscores the significance of pedagogical approaches in developing programming skills among students.

"*Task design for online learning: the case of middle school mathematics and science teachers*" (Daher et al.) examines task design in online learning environments. The study highlights the importance of well-structured tasks to facilitate effective online instruction.

"*Social robotics in music education: a systematic review*" (Martinez-Roig et al.) explores the role of social robotics in music education. The study emphasizes the potential of robotics to enhance musical learning experiences and bridge the gap between technology and the arts.

"*Lëttëra web platform: a game-based learning approach with the use of technology for reading competence*" (Uhlig et al.) focuses on game-based learning approaches to improve reading literacy. The study highlights the Lëttëra platform as a promising tool for enhancing reading instruction in secondary schools.

The research contributions presented in this editorial collectively highlight the multifaceted nature of educational digital transformation and the challenges it brings for competence development. The studies underscore the significance of well-designed and inclusive digital learning experiences, as well as the importance of preparing educators with the necessary digital competencies to deliver effective instruction.

The integration of technology, including video games, mixed reality, and social robotics, emerges as a promising approach to enhance student engagement and learning outcomes. These technologies offer new avenues for interactive and immersive learning experiences, catering to the diverse learning preferences of students.

The impact of the COVID-19 pandemic on education is a recurring theme in several contributions, reflecting the profound disruptions caused by the sudden shift to online learning. The studies examining the challenges faced during this crisis emphasize the importance of resilience and adaptability in the face of unforeseen circumstances. The lessons learned from these experiences can inform future crisis preparedness and educational continuity plans.

Addressing the digital divide remains a critical concern in the context of educational digital transformation. Studies such as "*The impact of the digital divide on synchronous online teaching in Kazakhstan during COVID-19 school closures*" (Amirova et al.) shed light on the unequal access to technology and digital skills, which can hinder students' participation and success in online learning. Bridging this divide requires concerted efforts from policymakers, educators, and stakeholders to ensure equitable access to technology and digital resources for all learners.

Teacher training and professional development play a crucial role in ensuring the successful integration of digital tools in the classroom. The research on "*Development of the teacher's technological pedagogical content knowledge (TPACK) from lesson study: a systematic review*" (Sierra et al.) highlights the significance of TPACK as a framework for preparing teachers to effectively leverage technology in their teaching practices. Investing in teacher training that focuses on digital competencies and pedagogical approaches is essential for empowering educators to create meaningful and impactful digital learning experiences.

The international perspective presented in "*Review on the teaching of programming and computational thinking in the world*" (Belmar a) underscores the need for global collaboration and knowledge sharing in advancing digital literacy and computational thinking education. Recognizing the disparities in the implementation of these subjects, especially in Latin America and Africa, calls for collective efforts to promote digital competence worldwide.

Moreover, student evaluations of teachers' digital skills, as explored in "*Student evaluation of teacher digital skills at Granada University,*" (Alonso-García et al.) demonstrate the importance of understanding and addressing educators' digital proficiency. Providing support and resources to teachers to enhance their digital skills fosters a conducive learning environment that harnesses the full potential of technology.

The adoption of gamified learning approaches, such as "*Enhancing cognitive combat readiness: Gamers' Behaviors concentrating on convergent learning style, tacit-latent, and kinetic-active knowledge acquisitions,*" (Sumiyana et al.) signifies the transformative potential of gaming in education. Leveraging gamification can enhance motivation, problem-solving skills, and critical thinking, making learning more engaging and effective.

Throughout the contributions, the need for a well-structured and thoughtful approach to digital learning design is evident. Effective task design, as explored in "*Task design for online learning: the case of middle school mathematics and science teachers,*" (Daher et al.) is crucial in creating engaging and meaningful learning experiences in virtual environments.

The intersection of technology and creativity is also evident in "*Social robotics in music education: a systematic review,*" (Martinez-Roig et al.) which underscores the importance of incorporating technology in the arts. By embracing social robotics in music education, educators can create novel and inspiring learning experiences that resonate with students.

While the research contributions provide valuable insights into the challenges and opportunities in educational digital transformation, they also pave the way for future research and exploration. As technology continues to evolve, it will undoubtedly present new challenges and possibilities for educational development.

In conclusion, the Research Topic "*Educational Digital Transformation: New Technological Challenges for Competence Development*" has highlighted the transformative impact of technology on education. The studies presented in this editorial underscore the significance of preparing students and educators for the digital era, fostering digital competencies, and creating inclusive and engaging digital learning experiences. The research also draws attention to the need for addressing the digital divide and ensuring equitable access to technology and digital resources. By embracing innovative technologies, such as social robotics and gamified learning, educational institutions can harness the full potential of digital transformation to enhance competence development and prepare learners for success in the 21st century (Romero-Tena et al., 2020; Pinto Santos et al., 2023). As the digital landscape continues to evolve, ongoing research and collaborative efforts are vital to ensure that educational digital transformation remains a catalyst for positive change and educational development.

Author contributions

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Conflict of interest

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

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Psychometric study of a scale on the use of video games for the initial training of teachers

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The present study is focused on analyzing the properties and psychometric characteristics of the Questionnaire about the use of video games in Higher Education. Specifically, in this work we focus on the use of a classic video game, such as Lemmings, to work on the curriculum of the Early Childhood Education stage. The instrument was created *ad hoc*, based on a Likert scale of 5 response options and three dimensions: student/player profile, quality of the video game and assessment of the video game as a teaching resource. Regarding validity, two studies have been carried out, one with an exploratory nature with half of the sample, 131 participants; and another confirmatory with the total number of the participants, 261 students from the Early Childhood Education Degree at the University of Córdoba (Spain), considering the convergent and discriminant validity coefficients. Lastly, a correlational study was also carried out to clarify the relationships established between the different dimensions of the questionnaire. The results achieved demonstrate that the instrument obtained had a coherent and adequate internal structure with the theoretical assumptions initially raised, as the goodness-of-fit indexes of the confirmed model were high, at the same time showing high validity and reliability.

KEYWORDS

validity, questionnaire, video game, childhood education, initial teacher training

Introduction

The use of the ICT in the classrooms has slowly but steadily become a reality for students and teachers, with its introduction promoted by their high use in every part of society and its great consumption at home (Marín Díaz and Martín-Párraga, 2014).

Currently, among the technological resources most utilized by the young population, we find videogames, defined as a game with an electronic component, whose aim is to entertain players, submersing them in 2D and 3D environments (Quwaider et al., 2019). They can be employed in various platforms such as videogame consoles, computers,

mobile phones, tablets, etc. (Martín del Pozo, 2013), and adapted to different tastes, which grants them with a great ability to be marketed (López, 2017).

Given their extensive use, many research studies have been conducted to analyze their efficiency at the educational level, among these studies, we find the study by Asociación Española de Distribuidores y Editores de Software de Entretenimiento (aDeSe) (2012), which conducted a study at the national level about the use of videogames for teaching, concluding that their use in this sector helped with the learning of specific subjects, the development of psychomotor and cognitive skills, and personal, social and moral skills as well. In turn, if their characteristics were analyzed in detail, their relationship with the structure utilized when designing an educational activity in the classroom could be visualized (Glover, 2013):

- Establishment of objectives. Just as with educational activities, where a series of objectives are set to be achieved by the student, or a competency to be acquired is defined, all the videogames define a series of objectives to be reached for the player to achieve victory, overcoming a series of obstacles for this.
- Awards. Different manners for recognizing the merits reached by the players are utilized, such as classifications, prizes, etc.; and if transported to the education arena, digital badges can be utilized that allow granting recognition to the students who behaved well, who had done the class activities well, etc. (Gibson et al., 2013).
- Progress. In every videogame, it is necessary to inform the player about which phase he is in as regard to progress, indicating the objectives achieved and those that remain. This also occurs in educational contexts, where feedback is essential, as the learners should be aware of the activities that are completed, and they should be guided with recommendations that help them in their learning process.

All of these characteristics make possible their use at the educational level, allowing for the development of aspects such as problem resolution, making of decisions, search and organization of information, etc. Also, learning through games is attractive for the students, especially in the first stages, when motivation during their use and a positive attitude during the work phase are generated, at the same time that it helps with the development of computational thinking (Carenys et al., 2017; Sampedro Requena et al., 2017; Morales Díaz, 2018; Garneli and Chorianopoulos, 2019). Likewise, they can enrich the initial process of reading in the first stages (Jiménez Porta and Diez-Martínez Day, 2018), and are an instrument for promoting the inclusion and collaboration among the learners (Marín, 2016; Sampedro Requena et al., 2017).

At the legislative level in Spain, the presence of videogames is mentioned in the Royal Decree (2006) 1630/2006, from December 29th, which regulates the minimum teachings in the second cycle of Early Childhood Education. It establishes the student's familiarization with this resource; and Organic Law (2006) 2/2006, from the 3rd of May, on education, which mentions the need for education administrations to foment experiences related to the ICT during the first cycle of Early Childhood Education.

Their presence at the curricular level and the benefits reported describe their usefulness as a resource that should be kept in mind for teaching, and this is why they are being utilized in teacher's initial training, with positive assessments by the students, despite their pointing out of deficiencies in competencies when using them as a teaching resource (Aznar-Díaz et al., 2017; Correa et al., 2017; Marín-Díaz et al., 2019), as the attitude of the teacher towards these types of resources has an influence on the efficacy and the degree of acceptance observed in the learner (Martí-Parreño et al., 2018).

The inclusion of videogames in initial training programs for educators can be conducted through education technology courses, where it is possible to use them as a didactic resource. An example of this is the course within which the study is framed, named "Media education and education dimension of the ICT", taught in the second year of Early Childhood Education at the University of Córdoba, which seeks the development of the following competences:

- CU2 Know and understand the level of the user in the area of ICT.
- CE7 Know the educational implications of the information and communication technologies, and in particular, of the television in early childhood.
- CM3.4 To critically analyze and incorporate the more relevant matters of current society that affect family and school education; social and educational impact of the audiovisual languages and the screens; changes in gender and inter-generational relationships; multiculturality and interculturality; discrimination and social inclusion and sustainable development.
- CM6.3 Address field analysis through an observational methodology using information, documentation and audiovisual technologies.
- CM7.2 To know about international experiences and examples of the innovative practices in Early Childhood Education.
- CM8.9 Foment experiences of initiation to information and communication technologies.
- CM10.5 Analyze the audiovisual languages and their educational implications. CM11.CM11.3 Monitor and keep track of the educational process, and, in particular, of teaching and learning through the mastery of the techniques and strategies needed.
- CM11.4 Relate theory and practice with the reality of the classroom and center.

Faced with the potential shown by the videogames, the present study sought to verify the usefulness of the videogame "Lemmings" for future teachers. For this, an instrument was designed starting from the benefits reported previously, and two instruments that had already been validated, which will allow the collecting of information about the usefulness of any type of videogame.

The first instrument used as the reference (Lorca-Marín et al., 2019), was comprised by 41 items distributed in 5 dimensions, which addressed aspects related to factors of affiliation, attitudes towards the game-oriented use of videogames, attitudes on the use of the videogame as a teaching resource, concepts about its game-oriented or teaching-oriented use. The instrument includes open-ended and close-ended questions, and has a high interjudge agreement (M = 3.5 over 4), a Kappa index of 0.843, and reliability of.649, as measured with Cronbach's Alpha.

As for the second instrument (Muñoz González et al., 2015), it is a Likert-type questionnaire with 5 response options, ranging from total disagreement to total agreement; it is composed by a total of 23 dependent variables that provide information about: if the creation of videogames with the CourseLab application helps in the inter-relation processes among the students, as well as their collaboration, communication and establishment of new relationships. It measures the difficulties and usefulness of the application for working on the curriculum and its efficiency for promoting motivation and autonomy, among other aspects. Lastly, it also includes independent variables relative to gender, age, possession electronic devices, and about the most-common place for internet access of the student. This instrument was validated through an analysis of internal consistency with Cronbach's Alpha, with a result of 0.866.

Ultimately, the aim of this study was to validate an instrument of measurement, which can be used with any type of videogame, which will allow us to gather information about the usefulness of the videogame "Lemmings", as perceived by future teachers of Early Childhood Education.

Methodology

To analyze the objective described above, the technical characteristics of the Questionnaire on the use of videogames in Higher Education, created *ad hoc* were validated and analyzed in order to gather data on the gamer profile of the individuals surveyed, the quality of the "Lemmings" game, and the assessment of its use as a teaching resource in the Early Childhood Education stage.

In total, two studies were conducted, one exploratory with half of the sample, and another confirmatory with the total sample selected for the research study, utilizing a cross-sectional, quantitative survey methodological approach and a deductive research strategy.

Lastly, the aim of this study was to validate a measuring instrument that allows for the collection of information about the usefulness of the videogame "Lemmings" perceived by future teachers of the Early Childhood Education stage.

Sample

For the selection of the sample, a probabilistic or convenience sampling method was utilized (Otzen and Manterola, 2017), as the students who the researchers taught during the academic year 2020-2021 were selected for the study.

The first study counted with a total of 131 participants, all of which were enrolled in the Early Childhood Education Degree. The age interval established was 18 years old to older than 26, with the following gender distribution observed (**Table 1**).

The second study counted with the participation of 261 participants, also enrolled in the Early Childhood Education Degree. Their ages ranged from 18 years old to older than 26, with the following gender distribution (**Table 2**).

TABLE 1 Distribution relationship between age and gender.

Age	Women	Men	Total
18 to 20 years old	96.3%	3.7%	41.2%
21 to 23 years old	94.1%	5.9%	38.9%
24 to 26 years old	100%	0%	11.5%
Older than 26	90.9%	9.1%	8.4%
			100%

TABLE 2 Distribution according to gender and age.

Age	Women	Men	Total
18 to 20 years old	97%	3%	38.3%
21 to 23 years old	96.2%	3.8%	39.8%
24 to 26 years old	100%	100%	14.2%
Older than 26	90%	10%	7.7%
			100%

Data collection instrument

For the collection of data, a questionnaire was created *ad hoc*, using as a reference the benefits reported by videogames in the literature reviewed and two already-validated instruments (Muñoz González et al., 2015; Lorca-Marín et al., 2019). This questionnaire was administered and completed by the students online and anonymously. It

was poly-thematic and counted with a series of close-ended questions with a Likert-type answer scale. This scale ranged from 1 to 5, with 1 indicating complete disagreement, and 5 complete agreement, for the three dimensions that shaped it: "Student/player profile", "Quality of the videogame" and "Assessment of the videogame as a teaching resource". In total, it was composed by 16 items structured in three dimensions (**Table 3**):

- Student/player profile: This dimension, composed by 3 items, is focused on collecting information such as if the individual surveyed likes to play videogames, if this is done habitually, and if he or she has played many videogames.
- Quality of the game: This dimension encompasses a total of 5 items that address aspects related to the quality of the videogame, to verify if it is entertaining and motivating, if it offers enough options for playing and for interaction with the user, and if it is able to maintain the players' attention.
- Assessment of the videogame as a teaching resource: This dimension is composed by 8 items destined to clarify if the videogame allows for the development of the objectives and contents of the curriculum in this stage, if it helps in the acquisition of abilities/skills for problem resolution, and in working with psychomotricity, and if it promotes the development of values, imagination and creativity, as well as the coordination between the students.

Lastly, the instrument also includes a series of independent variables related with the sociodemographic characteristics (age, sex), the game devices habitually used (PC, tablet, videogame console, smartphone, various), the manner of playing the videogames (alone, with another person, with two people, or online), the place where the videogames are usually played (home, friend's house, faculty, other places) and the time spent by the user for playing the videogame "Lemmings" in a day and in a week.

Procedure

The instrument described was constructed starting from the benefits of videogames reported in the literature reviewed, and also from two instruments used as references (Muñoz González et al., 2015; Lorca-Marín et al., 2019).

From the first instrument (Lorca-Marín et al., 2019), the following were taken into consideration, which were re-formulated in the Questionnaire on the use of videogames in Higher Education:

- Item 9. How many hours a week do you play? Its selection was due to the need to analyze if the time spent playing the videogame "Lemmings" had an influence when analyzing it.
- Item 11. In what device? This was used as a reference to see if the device used habitually by the student influenced the assessment of the videogame object of study.
- Item 14. How do you usually play? It was chosen to analyze the habits of the player.
- Item 32. Choose what aspects you believe promote or decrease the use of videogames from an overall point of view. In this item, elements are collected that are linked with motivation, interaction, ability to resolve problems, ability to make decisions, etc., with these elements taken into account when designing the questions in the questionnaires.

TABLE 3 Dimensions and items of the questionnaire.

Dimension	Items
Factor 1. Student/player profile	1. I like to play videogames.
	2. I habitually play videogames.
	3. I have played many videogames.
Factor 2. Quality of the game	4. The videogame is fun.
	5. The videogame captures all my attention.
	6. The videogame has a high degree of interaction (player/user).
	7. The videogame poses enough play options.
	8. The videogame is motivating.
Factor 3. Assessment of the videogame as a teaching resource	9. The videogame facilitates the acquisition of abilities/skills for the resolution of problems.
	10. The videogame promotes personal autonomy.
	11. The videogame facilitates the development of values.
	12. The videogame contributes to the development of psychomotricity.
	13. The videogame promotes the student's coordination.
	14. The videogame promotes creativity and imagination.
	15. The videogame allows the development of some of the objectives established in the education stage's curriculum.
	16. The videogame allows the development of some of the contents established in the education stage's curriculum.

With respect to the second instrument (Muñoz González et al., 2015), the following items were assessed:

- Item 9. Promotes interactions and collaboration among students. It has served as the reference for constructing the item that addresses the coordination ability among the students.
- Item 23. Videogames help develop the different proposed targets on the core curriculum for Primary Education established in Royal Decree 1,513. This was utilized as the model to establish the two items that mention the contribution of the videogame "Lemmings" for developing the objectives and contents of the curriculum in the stage of Early Childhood Education.

Once the instrument was created, the learning exercise designed was performed, which was comprised by the following phases:

- Initial contact with the videogame "Lemmings": As it is a classic videogame, launched in 1991, it is completely unknown to the students. Therefore, the first part consisted in getting to know the game's environment, the objective and its main characteristics.
- The adoption of the player role: in this phase, the students are asked to adopt the role of videogame player so that they can play various times. This will allow them to get to know the elements in depth, as well as the strategies, abilities and skills that are needed to achieve the object of study.
- Adoption of the teacher role. In this last phase, once the students fully understood the aspects and characteristics of the videogame, they were asked to take on the role of teachers. Thus, they were asked to analyze the objectives, contents, competencies and evaluation criteria established by the curriculum in this learning stage and to design a teaching proposal, whose activities refer to the videogame learned.

At this time, it should be taken into account that these phases required a considerable period time, so that the learners needed to have enough time to understand the videogame and to design the activities. More specifically, in the study, the total time employed was 15 in-person hours.

Data analysis

The analysis process encompasses two studies:

a) Study 1. It is based on the pilot application of the questionnaire so that it could be adapted and contextualized to the target population. The pilot test allowed for the analysis of its factorial structure and the detection of possible problems of comprehension of some of its items, as well as its index of discrimination. The questionnaire was completed by the students through the Google Forms software, after they tried the videogame "Lemmings". With the data collected, the normality of the sample was verified with the Kolmogorov-Smirnov test, obtaining a value of $p > 0.05$, making its normalization unnecessary (García et al., 2010). Afterwards, an exploratory factorial analysis (EFA) was performed with the statistical programs SPSS 23 and Factor Analysis (10.8.04), utilizing Pearson's correlation matrices, along with the "Optimal implementation of parallel analysis" (PA) (Timmerman and Lorenzo-Seva, 2011) to determine the number of factors, and the "robust non-weighted squares" with "Promin" rotation procedure (Lorenzo-Seva, 1999).

b) Study 2. After the end of the first study, a confirmatory analysis was performed starting with the total research sample, with was selected following the same procedures described for study 1. In this case, the normalization of the sample was needed, and this was done through the elimination of outliers using the Mahalanobis test (AMOS 23), which reduced the size of the sample from 261 participants to 255. The sample was comprised of 246 women and 9 men, with an average age of 19.1 and a standard deviation of.911. Afterward, the same software was utilized for the creation of structural equation models, in order to assess the adjustment of the model through the use of the following statistics tests: $\chi 2$/degrees of freedom (Schumacker and Lomax, 2004), comparative fit index (CFI), incremental fit index (IFI), normed adjustment index (NFI), the Tucker-Lewis index (TLI) (Byrne, 1994, 2001; Hu and Bentler, 1999), the root mean square error of approximation (RMSEA) (Hu and Bentler, 1998) and the expected cross validation index (ECVI). The validity and reliability of the instrument was also analyzed through the use of the software cited, through the following indices: Reliability coefficient H (MaxR(H)), Average Variance Extracted (AVE), Maximum Shared Variance (MSV) and Compound Reliability (CR). With these data, the convergent and discriminant validity of the instrument designed was found. Lastly, the existing relationships between the dimensions of the instrument was verified through a correlational analysis.

Results

Once the analysis was completed, the results obtained and structured from the studies performed for the validation of the

TABLE 4 Matrix of rotated factors.

Variable	F 1	F 2	F 3
V 1	0.810		
V 2	0.906		
V 3	0.776		
V 4		0.793	
V 5		0.936	
V 6		0.568	
V 7		0.596	
V 8		0.516	
V 9			0.473
V 10			0.541
V 11			0.684
V 12			0.744
V 13			0.619
V 14			0.436
V 15			0.984
V 16			0.957

Questionnaire on the use of videogames in Higher Education will be described below.

Study 1

The EFA conducted allowed us to analyze the internal structure of the instrument with the theoretical structure from its initial version, obtaining important data for the study of the validity of the construct that allow us to improve the questionnaire starting with the information collected. For this, its viability was confirmed through the determination of a correlation matrix of 0.00; KMO = 0.851; Bartlett's Sphericity test with a significance of 0.000 and a root mean square residual = 0.0485.

After these criteria were verified, the EFA was applied to the original version of the questionnaire, with 16 items and 3 dimensions, adjusting the factors to be extracted to 3. The analysis shows that the factors extracted explained 50.27% of the variance, with commonalities that oscillated between 0.380 for item 6 to 0.826 for item 15. At the same time, if the matrix of rotated elements and the weight of each factor is viewed (**Table 4**), their correspondence with each of the dimensions taken into account in the study, with loads higher than 0.3 in each item, is visualized.

As for the internal reliability of the instrument, Cronbach's Alpha coefficient was utilized (Merino-Soto, 2016), for the instrument in general ($\alpha = 0.876$), as well as for the three factors extracted ($\alpha = 0.878$ for factor 1; $\alpha = 0.814$ for factor 2 and $\alpha = 0.877$ for factor 3) to determine their internal consistency, with a high reliability obtained.

Study 2

To compare and contrast the data from the previous study, a confirmatory factor analysis (CFA) was performed with the Maximum Likelihood method, with which the following results were obtained (**Figure 1**).

Afterwards, the goodness-of-fit of the model was verified, with the $\chi 2$/degrees of freedom test, the comparative fit index (CFI), the incremental fit index (IFI), the Tucker-Lewis index, the root mean square error of approximation (RMSEA) and the expected cross validation index (ECVI). The results obtained were the following (**Table 5**).

Based on the indices showed on the table, the results are deemed to be adequate, as the $\chi 2$ has a probability of.00, with values lower than.06 in the RMSEA, and higher than.90 in CFI, IFI, NFI and NNFI (Byrne, 2005; Arias, 2008). These data allow guaranteeing the validity of the construct of the instrument designed, confirming the model of factors proposed.

As for the coefficients of reliability and validity found through the analysis of the standardized regression loads and the correlations obtained with the AMOS 23 program, it could be stated that the results were adequate, taking into consideration the items that comprise each factor (**Table 6**), Reliability: CR $>$ 0.7; Convergent Validity: CR $<$ AVE, AVE $>$ 0.5; Discriminant validity: MSV $<$ AVE and MaxR (H) $\geq$ 0.70.

To conclude, its internal consistency was analyzed in a general manner as well as in each of its dimensions through Cronbach's Alpha, and from the data obtained (**Table 7**), it is observed that each of the dimensions had a coefficient higher than.8, which allows the confirmation that in general, as well as in each of the dimensions, the instrument had a high internal consistency (Thorndike, 1997).

Correlational analysis

The existing correlation between the three dimensions that comprise the questionnaire was studied through Pearson's correlation. The data obtained can be observed below (**Table 8**).

The results found show that there is a relationship, although weak, between dimension 1 (Student/player profile) and dimension 2 (Quality of the videogame) and dimension 3 (Assessment of the videogame as a teaching resource) ($R = 0.29$ and $p = 0.00$; $R = 0.15$ and $p = 0.02$, respectively) (Mateo, 2004; Pérez et al., 2009). At the same time, there is a moderate correlation between dimension 2 (Quality of the videogame) and dimension 3 (Assessment of the videogame as a teaching resource) ($R = 0.56$ and $p = 0.00$).

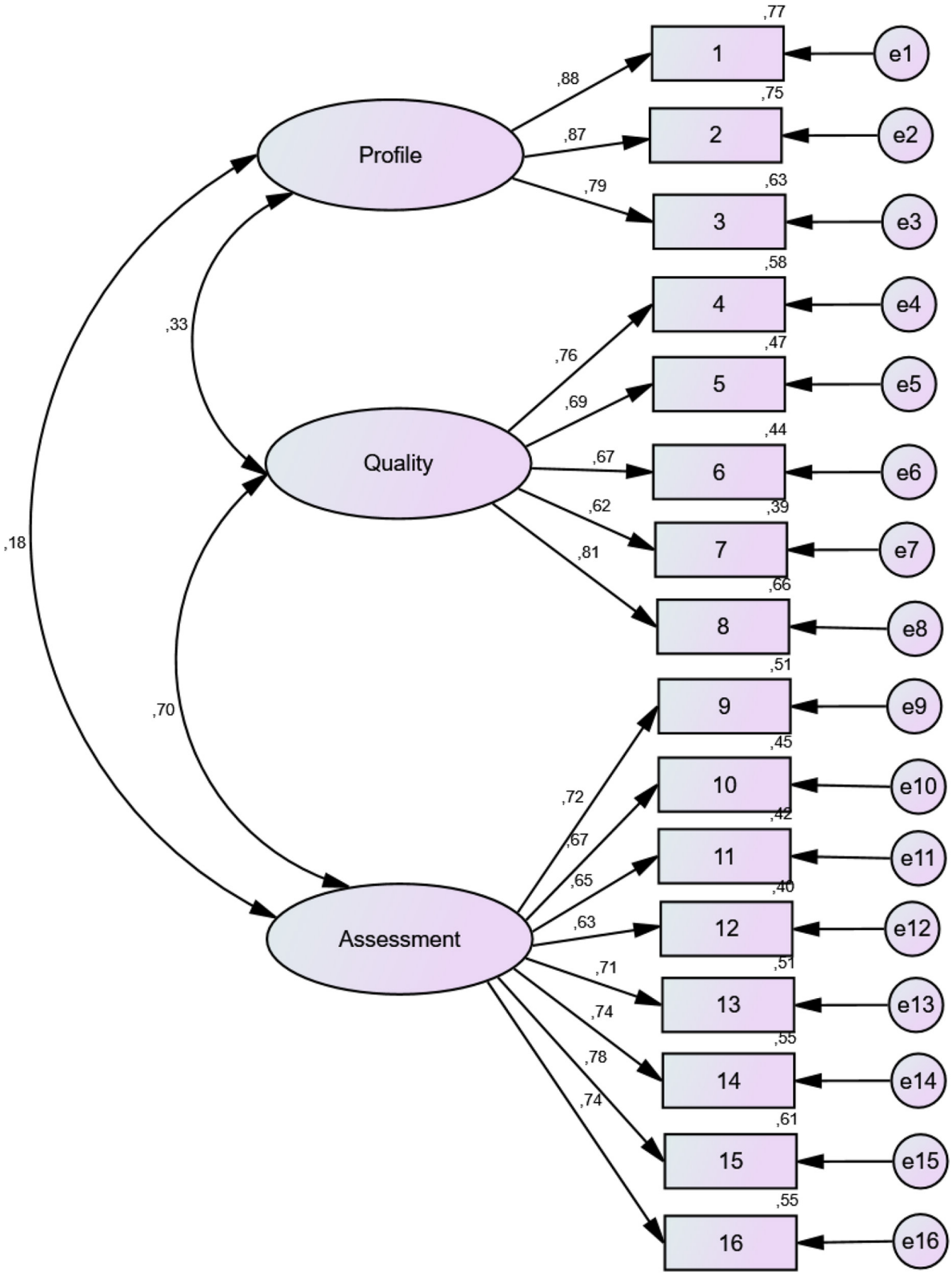

FIGURE 1
Three factor model (CFA).

TABLE 5 Adjustment indices of the model.

	χ2	*df*	*p*	X^2/df	CFI	IFI	NFI	NNFI (TLI)	RMSEA	ECVI
Values	133.98	79	0.00	1.69	0.98	0.98	0.95	0.96	0.05	1.12

TABLE 6 Validity and reliability coefficients of the 3-factor model.

	CR	AVE	MSV	MaxR(H)	Assessment	Quality	Profile
Assessment	0.889	0.502	0.484	0.893	0.708		
Quality	0.837	0.509	0.484	0.933	0.696	0.713	
Profile	0.883	0.716	0.107	0.957	0.179	0.327	0.846

TABLE 7 Internal consistency of the instrument.

Dimension	Reliability
Factor 1. Student/player profile.	α = 0.88 (*n* = 3)
Factor 2. Quality of the videogame.	α = 0.84 (*n* = 5)
Factor 3. Assessment of the videogame as a teaching resource.	α = 0.89 (*n* = 6)
Total	α = 0.89 (*n* = 16)

Discussion and conclusions

The questionnaires utilized as a reference (Muñoz González et al., 2015; Lorca-Marín et al., 2019), together with the literature highlighted in the introduction of the present article, have allowed the creation of the Questionnaire on the use of videogames in Higher Education. The results obtained, after the EFA and CFA performed, allowed confirming that this instrument is reliable for compiling information about the player profile of the students enrolled in the Early Childhood Education degree from the Faculty of Education at the University of Córdoba; as well as to evaluate the quality of a videogame, and to gather data about their assessment on its use in the Early Childhood Education classroom.

As opposed to the two instruments that were utilized as the basis for its creation, this study has contributed data on the convergent and discriminant validity of the construct, through statistical data on composite reliability, average variance extracted, maximum shared variance (MSV) and reliability coefficient H (MaxR(H)). Likewise, a correlation analysis was performed between the three dimensions that comprised the questionnaire, verifying the existence of a relationship between them.

Lastly, as for the model confirmed, the structure of the instrument was composed by three dimensions:

- Dimension "Student/player profile". This dimension was composed by a total of 3 items, which measured if the student liked to play videogames, if the student did so habitually, and if the student had played many of them. It was created to detect the students' contact with it, as studies have been found which indicate that university students also spend time with this type of entertainment (Gómez-García et al., 2017; Lorca Marín et al., 2017; Dindar, 2018; Maja Ružić-Baf, 2018; Marín-Díaz et al., 2019), with their

TABLE 8 Results of the bivariate correlations of the items from the 3 dimensions of the questionnaire.

		Student/ player profile	Quality of the videogame	Assessment of the videogame as a teaching resource
Student/player profile	N	255	255	255
	Pearson's correlation	1	0.29**	0.15**
	Sig. (two-way)		0.00	0.02
Quality of the videogame	N	255	255	255
	Pearson's correlation	0.29**	1	0.56**
	Sig. (two-way)	0.00		0.00
Assessment of the videogame as a teaching resource	N	255	255	255
	Pearson's correlation	0.15**	0.56**	1
	Sig. (two-way)	0.02	0.00	

**. The correlation is significant at.01 (two-way).

use being more common among men (Asociación Española de Videojuegos (AEVI), 2018; Dindar, 2018; Marín-Díaz et al., 2019).

- Dimension "Quality of the videogame". This was composed by 5 items which evaluated the quality of the videogame, referring to the entertainment it provides, the ability of capturing the player's attention, the degree of interaction offered to the user, if it has enough options of play, and if it is motivating for the student.
- Dimension "Assessment of the videogame as a teaching resource". This dimension was comprised by 8 items, which collected information on the assessment of the videogame by the students related to the acquisition of abilities and skills for problem resolution; the ability to promote autonomy, the development of values, psychomotricity, and creativity; and if it allows the development of objectives and contents of the curriculum of the Early Childhood stage. The aspects evaluated in this dimension correspond to the benefits contributed by the videogames to this educational stage, observing that they contribute, among other things, with the motivation of the learners and the development of attitudes of collaboration (Sampedro Requena et al., 2017). Likewise, future teachers highlight that they can be used in specific instances in the classrooms, thanks to the curricular competencies such as digital competency, mathematical competency and the basic competencies in science and technology allowing their integration into the curriculum (Aznar-Díaz et al., 2017). In fact, the videogame "Lemmings", utilized to validate this instrument, could be useful for working with the early childhood curriculum in a cross-disciplinary manner (Marín Díaz and Martín-Párraga, 2014).

Ultimately, the instrument assessed in the present study has been confirmed as a reliable means for compiling data related to the player/student profile and for assessing the quality and usefulness of a videogame in the Early Childhood Education stage. Nevertheless, given that the sample was concentrated in the Early Childhood Education Degree from a single university, its functioning with a large sample is unknown. Thus, its use with a greater sample which encompasses other universities, should be the focus of future research.

Data availability statement

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

Author contributions

MRE: conceptualization. JMG: investigation. CAC: methodology. MHA: writing. All authors contributed to the article and approved the submitted version.

Conflict of interest

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

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Publisher's note

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A qualitative exploration of university students' perspectives on distance education in Jordan: An application of Moore's theory of transactional distance

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The current study aimed at exploring university students' perspectives on the emergency distance education strategy that was implemented during the COVID-19 crisis in Jordan, one of the countries in the Eastern Mediterranean Region. Utilizing a qualitative design supported by Moore's theory of transactional distance, a total of 17 semi-structured interviews were conducted with university students of various study levels and disciplines. Data were inductively analyzed using thematic analysis as suggested by Braun and Clarke. Seven themes have emerged, including, (i) students' psychological response to the sudden transition in educational process, (ii) students' digital preparedness, equality, and digital communication, (iii) students' and teachers' technical competencies and technostress, (iv) student–student and student–teacher interpersonal communication, (v) quality and quantity of learning materials, (vi) students' assignments, examinations, and non-reliable evaluation methods, and (vii) opportunities with positive impact of distance learning. The study findings provide evidence that the sudden transition from traditional on-campus to online distance education was significantly challenging in many aspects and was not a pleasant experience for many participants. Various factors under the jurisdiction of academic

institutions and decision-makers are considered main contributing factors to the students' educational experiences amid the pandemic crisis. Therefore, better planning and more sustainable utilization of educational resources have paramount importance in providing a high-quality education. Additionally, more dedicated efforts in terms of equitable, reliable, and credible evaluation systems should be considered in Jordan's distance education strategy.

KEYWORDS

digital preparedness, Jordan, COVID-19, qualitative, distance education, Moore's theory, transactional distance

Introduction

It has been over two years since the greatest global disruption of education due to the coronavirus disease-2019 (COVID-19) crisis. Most campuses of various educational institutes were closed and switched to online distance education mode, starting a new era in educational history (Barakat et al., 2022; Ellakany et al., 2022; Mohammed et al., 2022). Developed countries were more prepared for the unprecedented transition in many terms, such as quality of internet services, technical competencies of instructors, and the experience in online education during the pre-pandemic era. On the other hand, developing countries were less prepared and faced more challenges in implementing the new teaching model due to unreliable technical infrastructure and financial costs (El Said, 2021; Barakat et al., 2022).

Many studies tried to capture the perspective of students and instructors toward the online experience aiming to improve the learning deliverables and increase the outcomes through comparing distance online education versus face-to-face education in developed countries (El Said, 2021). While the entire world switched to online distance education during the pandemic crisis, few studies tried to capture the impact of this switch on students and teachers in developing nations. The studies mainly focused on the students' attitude toward online learning, especially for students with practical courses. Students' feedback and experience were mixed between positive and negative. Many students commented on the instructors' ability to provide online lessons and use technology to provide the best educational outcome (Hussein et al., 2020; Khalil et al., 2020). Many teachers have limited technological skills resulting in difficulties in providing virtual aids to present the lectures; thus, affecting the teaching quality. Also, some students expressed that they are on-campus learners and online lessons are not a fit for them (Al-Balas et al., 2020; Hussein et al., 2020; Khalil et al., 2020; Suliman et al., 2021). When it was related to practical courses, such as in engineering, medicine, and nursing, many students reported dissatisfaction as they believed they lost the chance to learn essential skills for their future careers (Sindiani et al., 2020; Ibrahim et al., 2021; Suliman et al., 2021).

Additionally, many studies in the Eastern Mediterranean Region (EMR) highlighted a worsening in the psychological wellbeing of students due to lockdown, study load, and concerns about the future and career, which resulted in lower energy and higher distraction while attending virtual courses (Al-Tammemi et al., 2020; Hussein et al., 2020; Alsoud and Harasis, 2021; Fawaz and Samaha, 2021; Suliman et al., 2021). Moreover, many students experienced more homework and assignments than in face-to-face education, assuming that students have more time to study due to the lockdown resulting in fewer achievements and more anxiety (Hussein et al., 2020). The level of satisfaction toward distance online education was found to be related to having previous experience in online learning. In contrast, students without former experience may need some time to adapt to the new learning model (Sindiani et al., 2020). Considering the pandemic crisis, students may perceive that online education is safer than the traditional face-to-face one; however, this can be particularly applicable to pandemic or conflict scenarios, and not for ordinary life (Hussein et al., 2020).

Even with the global race in digitalization and distance education within the past decades, many developing countries of limited resources seem struggling to keep up with the global pace. Arab countries were not an exception to be severely afflicted by the pandemic and its consequences on education, health, economy, and social life (Al Nsour et al., 2020; Akour et al., 2021a; Khatatbeh et al., 2021b; Undp., 2021; El Abiddine et al., 2022). In light of the previously described challenges and considering that most studies about online distance education in the Arab region were of a quantitative nature, the present study aimed at exploring the university students' perspectives on the emergency remote education that started in response to the COVID-19 crisis using a qualitative approach to gain an in-depth understanding of the lived experiences amongst students.

Materials and methods

Study setting and population

Our study was conducted in Jordan, one of the Arab countries located in the WHO EMR with a total population of

11.2 million (Department of Statistics., 2020). Jordan is classified as a middle-income country according to the World Bank. The official spoken language in the country is Arabic. The study population comprised students who were officially enrolled in a study program at any of the public or private universities in the academic year 2019/2020 or 2020/2021 (the academic year usually starts in September and ends in June with some minor variations between public and private universities in the country). The implementation of emergency distance education in Jordan has started in the middle of March 2020.

Study design and theoretical framework

An exploratory qualitative design with a framework based on Moore's theory of transactional distance was employed in the current study. Utilizing a qualitative approach was agreed on to get an in-depth understanding of the university students' lived experiences and opinions during the unprecedented transition from traditional on-campus education to distance education during the nationwide lockdown in Jordan. Additionally, the authors adopted the theory of transactional distance as a theoretical model to facilitate a more systematic exploration of the students' experiences. This theory was originated in the 1970s by Moore (2018). Transactional distance is defined as "the physical distance that leads to a communications gap, a psychological space of potential misunderstandings between the behaviors of instructors and those of the learners" (Moore and Kearsley, 1996; Chen, 2001). In 1989, Moore pointed to three domains of interactions that present in distance learning, including *learner-instructor interaction*, *learner-learner interaction*, and *learner-content interaction* (Moore, 1989). Later in the 1990s, Hillman, Wills, and Gunawardena had taken Moore's theory into a more advanced step by adding a fourth domain of interaction that is, *learner-interface interaction*, considering the interaction that occurs between students and technology in the telecommunication era (Chen, 2001). Accordingly, we adopted the four domains for a more systematic approach in addressing our study objectives. **Figure 1** illustrates more details about the four domains of the above-mentioned interactions.

Sampling

Students were purposively recruited with maximum variation sampling to capture a diverse and wide spectrum of views and lived experiences relating to online distance education. A web-based advertisement that described the nature and objectives of the study along with eligibility criteria was disseminated to student groups on Facebook®. University students in Jordan created these groups as a tool for general and academic communication. Students aged 18 years and above, and who experienced the COVID-19 enforced distance education from various Jordanian universities, study programs, and study levels were encouraged to enroll in the study. Students who declared their interest to participate were asked to fill out a brief online questionnaire that collected basic sociodemographic data (age, gender, residence region, and contact details) and educational profile (public or private university, study program, and study level). Additionally, the online questionnaire included a written informed consent regarding voluntary participation, interviews recording, and consent to publish quotes.

Data collection: semi-structured interviews

A total of 17 semi-structured individual interviews were conducted with students in the period of September–December 2020. To facilitate data collection, an interview guide which was created by the authors based on the four constructs of Moore's theory of transactional distance was utilized (Supplementary Appendix 1). The interview guide was further inspired by the students' reactions and comments on various social media platforms during the implementation of distance learning.

Given the unfolding situation of the COVID-19 pandemic and the associated control measures, to limit physical contact with students due to the pandemic, and to eliminate any geographical boundaries aiming to reach participants from different Jordanian governorates, the interviews were conducted using voice over internet protocol (VoIP) via Zoom® videoconferencing platform.

The interviews were conducted at a suitable time that was determined by each student based on the student's availability and daily schedule. All interviews were conducted in Arabic (the national language of Jordan), and verbal consent was obtained from all students at the beginning of each interview as a pre-requisite for starting the recording process (along with the written consent provided in the online questionnaire).

Various probing techniques were employed to encourage the students to explicitly express their opinions, stories, and experiences. The researchers closed the interview by asking the students whether they wanted to add any further information. The average duration of an interview was around 38 min, and the sampling process continued until data saturation was achieved. No incentives or rewards were provided upon participation. Students who agreed to participate in the study came from various educational backgrounds and study programs including both medical programs (i.e., Medicine, Pharmacy, Dentistry, Medical Laboratory Sciences, Nursing), which involve both theoretical and practical sessions, as well as non-medical programs related to arts and humanities, engineering, and sciences (i.e., Law, Literature and Languages, Engineering, Natural Sciences, Childhood Education, Mathematics, Biology, Biotechnology, Psychology,

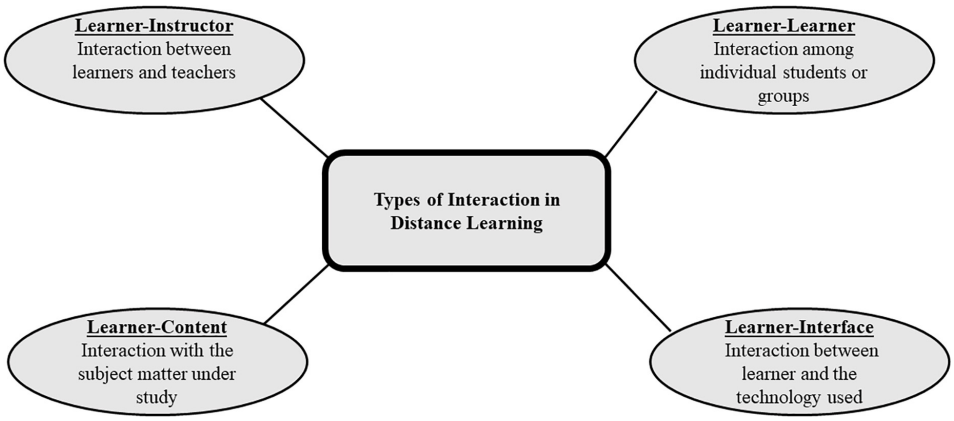

FIGURE 1
The four types of interactions that occur in distance learning. Moore's theory of transactional distance was adopted as a framework in our qualitative approach.

Economics). Many of the non-medical programs have also theoretical and practical sessions (e.g., Biology, Biotechnology, Engineering, Natural sciences). Additionally, during the pandemic crisis and the transition to distance education at the time of conducting the current study, all the courses were delivered virtually as synchronous and/or non-synchronous sessions, due to the complete closure of all higher education campuses in the country. The characteristics of participants are presented in **Table 1**.

Data management and analysis

The recorded interviews were transcribed verbatim (in Arabic) by three researchers who have prior experience in qualitative research. Then, transcripts were analyzed inductively using thematic analysis as suggested by Braun and Clarke (2006). This involved familiarization with the transcribed data, assigning preliminary codes, merging codes into themes, reviewing themes, defining and naming themes, and lastly reporting themes. Data coding and analysis were conducted by the same researchers who conducted the interviews. Discrepancies in coding were discussed by the team and resolved by reaching a consensus. For reporting purposes, selected quotes were translated into English by two bilingual translators using translation and back-translation technique. Moreover, we adhered to the Consolidated Criteria for Reporting Qualitative Research (COREQ). **Table 2** describes the coding scheme of the implemented analysis.

Study rigor and trustworthiness

Despite that replicability is not a characteristic of qualitative research, unlike in the quantitative one, various techniques have been discussed in the literature to enhance the trustworthiness of qualitative research findings and methodology (Lincoln et al., 1985). Accordingly, and for ensuring the rigor and trustworthiness of the present qualitative study, Lincoln and Guba (1985) criteria were adopted, and this involves credibility, dependability, transferability, and confirmability. Peer-debriefing, using quotations, prolonged engagement with participants as well as the explicit statement about confidentiality, all were utilized to establish credibility. Also, peer-debriefing between researchers who conducted and analyzed the interviews was used to enhance dependability, and confirmability. Additionally, enhancing transferability was sought through the detailed description of the study context and participants, justifying the sampling strategy as well as describing data collection procedure and analysis.

Ethical considerations

The ethical approval for conducting our study was obtained from the institutional review board of the Deanship of Scientific Research at the University of Jordan with a reference number (IRB# 310/2020/19). Also, all study procedures were conducted conforming to the ethical standards of the Declaration of Helsinki. The recorded interviews as well as the transcripts were encrypted with a password and kept securely. Moreover, written, and verbal informed consent was obtained from all participants regarding voluntary participation, recording the interviews, and consent to publish quotes.

Results

Seven themes have emerged from the transcribed data of the 17 interviews as the following:

Theme one: Students' psychological response to the sudden transition in educational process

Students during the COVID-19 pandemic crisis were put in a new educational experience during the enforcement of emergency online education and the closure of higher academic institutions in Jordan. This unprecedented transition in the educational system has forced most students to have various emotional responses. When students were asked to recall how they felt when receiving the news about the implementation of online distance education, they described various feelings. Their feelings were attributed to many reasons as well.

A pharmacy student said:

> *"I just felt happy when I knew that the university will be closed, and all our classes will be delivered virtually. . .I no longer need to spend more time and money on public transportation. I will have more time to study too"*

Also, another student who studies at the faculty of language studies expressed being happy due to shifting to online education. The student perceived this as a precautionary measure against COVID-19 and unnecessary interpersonal interactions:

> *"It was great news when I heard that I will not attend on-campus classes because this will reduce face to face communication; thus, avoiding the exposure to the coronavirus"*

However, an engineering student expressed mixed feelings when receiving the news about closing universities:

> *". . .I had a mixed feeling surrounded by fear, anxiety, and some sort of happiness at the same time. . .I felt that I will be going through an uncertain academic journey"*

On the contrary, a group of students expressed more negative feelings toward the emergency transition in the educational process. This was mostly attributed to the affection of the usual learning process, especially regarding practical sessions. A student who studies nursing said:

> *"An unexpected situation. . .I was supposed to attend the hospital for my practical training. . .I felt anxious at that time. . ."*

Additionally, a student who attends a medical laboratory sciences program stated:

> *"I thought it was good news at the beginning, but with time and all of a sudden, I realized I was not well prepared for the transition"*

Moreover, a student who attends medical school said:

> *"It was shocking to hear that! I did not know what will happen to my practical sessions in the hospital.I am about to graduate, and this is a very critical period in my academic journey. . . I am very stressed"*

Theme two: Students' digital preparedness, equality, and digital communication

The transition to distance education was an unprecedented decision. Students have to prepare and equip themselves with digital equipment to meet the requirements of attending their virtual classes. However, this was not easy for many of them. A student who studies psychology said:

> *"I bought a new headset and camera to facilitate the communication and learning experience during my virtual classes. . ."*

Also, another student from the faculty of sciences expressed difficulty in preparation for distance education:

> *"Our family has three students at university, and we have only one laptop. You cannot imagine how it feels when we have an overlapping lecture schedule! Using smartphones for virtual classes is not always friendly.this is not suitable"*

Having digital equipment, and other required accessories for online education was a challenge for students who suffer from financial constraints. A student who studies economics said:

> *"I used to have my laptop, tablet, and smartphone.same as my other siblings in the family. . .However, many students cannot afford to have all or some of these. . .governmental support to vulnerable students was not sufficient. . .This is unfair"*

Moreover, students were forced to rely solely on digital communication during distance education, and this has forced them to experience an increase in their usage level of virtual platforms. A medical student expressed the following:

> *"I started to be more committed to using my electronic devices during distance education.checking various learning platforms, my email, and many academic groups on social*

> *media to be able of managing the required studying duties and assignments. . .”*

Theme three: Students' and teachers' technical competencies and technostress

As the process of transition to distance education was unplanned and enforced due to the pandemic situation, many challenges were expected to be faced. One of these challenges was related to technical aspects. The students have used various online platforms such as Microsoft Teams®, Zoom®, and Moodle® to attend their virtual classes, submit assignments, and set for examinations. Most participants expressed that these online utilities were friendly and easy to use, while other students pointed to various challenges. Some of which were the lack of high-quality internet services in certain geographical areas, some platforms need sufficient digital skills to be used, non-sufficient technological competencies of many teachers, and non-sufficient digital resources/machines (e.g., laptop, desktop, etc.), especially when having many members who attend online distance education in the same family.

A biology student said:

> *“I regularly use the online platforms provided by my university.these platforms are easy to use considering having a sufficient level of digital literacy”*

Also, another student from the faculty of dentistry added the following:

> *“I am very comfortable with using online platforms, I can mute my microphone and turnoff my camera when no necessary interaction is needed”*

On the other hand, many students expressed that they experienced unfriendly situations when the internet suddenly disconnects, and this might have severe impacts, especially during online exams. A student who attends an early childhood education program said:

> *“This is not right. How could I maintain smooth progress in my learning while being stressed about internet connectivity issues! I heard about a student who failed the exam due to a sudden interruption in the internet connection. . .”*

Moreover, a mathematics student expressed difficulty in attending virtual classes. This was partially attributed to the level of digital skills of some teachers:

> *“Some virtual platforms have a non-friendly user interface that needs high digital skills. . .Also, some teachers do not know how to use these platforms. . .they need some training to improve their technical competencies. . .”*

Also, many students have faced difficulties in attending their classes due to the heavy burden on the internet services in the country. An engineering student said:

> *“Imagine when hundreds of thousands of students from various universities in Jordan attend virtual classes at the same time during midday. . . a huge load on the internet service providers and the losing side is us, the students”*

Theme four: Student-student and student-teacher interpersonal communication

The COVID-19 pandemic has resulted in a paradigm shift concerning interpersonal communication in the entire world. Due to various confinement and control measures, people including students were forced to maintain physical distancing and to limit face-to-face social interaction. University students were not an exception. Students have used virtual platforms to interact with their peers and teachers during the closure of universities in Jordan. However, this was not a smooth transition, and many students reported interpersonal communication challenges. A medical student said:

> *“Oh my God, communicating with teachers is becoming more difficult. I feel lost due to being enrolled in many virtual groups for various classes. . .On-campus classes are more suitable”*

Additionally, another student from the biotechnology program has expressed the following:

> *“. . .Some teachers responded very late to my emails, while in the university campus I was going to the teacher during office hours for most of my inquiries. . .”*

Some students have also described major impacts on communication with their colleagues. A psychology student said:

> *“I experienced a better communication with people during on-campus education. . .at the university, I have more engagement with my colleagues and teachers. Now in distance*

> *education. . .not enough activities or socialization. . .this is boring. . .”*

Most of the interviewed students referred to a problem related to misuse of learning platforms by some students. A student who attends an engineering program shared the following:

> *“. . .This is not funny at all! While the transition to distance education is a critical stage amidst the pandemic, some students perceive virtual classes as a place for fun and jokes. . .Some students were intentionally too noisy with their unmuted microphones. . .students should take distance education more seriously”*

On the contrary, some students have more positive experiences with virtual communication. A nursing student said:

> *“. . .I believe that some teachers have provided some sort of support regarding distance education. They tried to make student-teacher communication easier. They created groups on social media platforms to communicate with us regarding our study materials”*

Theme five: Quality and quantity of learning materials

In this theme, students have disclosed various opinions regarding the quality and quantity of the educational materials provided to them during remote online education. A medical student said:

> *“Sometimes I felt overwhelmed with the number of educational materials provided. The professors try to increase the lectures load in terms of content, believing that students have more time to study during the lockdown. . .this was different compared to what I experienced in the university campus”*

Also, an engineering student has had trouble in remote experimental sessions:

> *“The presentations and study materials were somehow not sufficient especially for my practical sessions”*

Additionally, another student in medical laboratory sciences said:

> *“Most lectures were provided as a PowerPoint presentation or PDF with good visualization. However, some study materials were more advanced than what is supposed to be received during on-campus education. . .I do not understand the reason behind this”*

On the contrary, some students felt that the study materials provided during remote online education were sufficient. An English literature student said:

> *“In my opinion and experience, I feel that the quantity and quality of the study materials provided to me were the same as during on-campus education. . .this is good enough to me”*

Theme six: Students’ assignments, examinations, and non-reliable evaluation methods

In this theme, most of the interviewed students described the evaluation methods and examinations in distance education to be non-reliable. A law student said:

> *“Cheating is a remark of distance education in our country. . .students can cheat in all remotely conducted exams as there is no reliable method to monitor students’ activities during distance examinations”*

Another student from the faculty of medicine said:

> *“Students are calling each other to solve online exams. . .how is this supposed to be a quality education?!”*

As cheating in online exams was described as a remark of online distance education in Jordan, some students experienced a high degree of difficulties in other evaluation methods such as assignments. An engineering student said:

> *“Too many lectures and assignments. I must submit many assignments every week. . .teachers have realized that many students cheat during remotely conducted online exams, thus, they tried to push the students to prepare more assignments as a better and more reliable evaluation method. I believe this is not working well too”*

Additionally, a nursing student said:

> *“Students are getting high end-semester grades during online distance education compared to on-campus education and examinations. This warns of a severe deficiency in the credibility and reliability of distance examination methods. . .a big failure in the monitoring system too”*

Theme seven: Opportunities with positive impact of distance learning

Despite the tough transition to online distance education, many students have seen various opportunities that positively impacted their academic journey. A medical student said:

> *"I feel that I have a better engagement with my studies. Now, I have more time to study than that when I had to go to the university campus"*

Another student from the faculty of language studies described online education as a flexible learning opportunity:

> *"Learning during online distance education is more comfortable. . .even timing of lectures is flexible too"*

Moreover, it seems that the transition to online education has enhanced the learning skills and abilities of some students. A student from the faculty of sciences said:

> *"Online education has enhanced my searching skills including using scientific websites in preparing my assignments. . .I feel that this experience has improved my self-learning skills and abilities"*

Furthermore, a law student expressed the following:

> *"During online distance education, I feel more comfortable as I can dress more comfortably compared to university dressing. Also, I realize that my facial skin is becoming healthier as I am currently avoiding hot weather during my supposed on-campus summer classes. . .no more on-campus attendance during summer. . .this is perfect for me"*

Discussion

The COVID-19 has overwhelmed many countries due to its high contagiousness and rapid spread as well as the control measures that most countries were forced to implement to mitigate or retard the spread of this disease (Al-Tammemi, 2020; Wendelboe et al., 2020). This global pandemic has not only resulted in biological or psychological harm, but also in dramatic changes that severely afflicted many sectors and industries globally, including healthcare provision, economy, social life, travel, and education (Al-Tammemi, 2020; Akour et al., 2021a,b; Aljaberi et al., 2021; Alrawashdeh et al., 2021; Fares et al., 2021; Folayan et al., 2021a,b; Garbóczy et al., 2021; Khatatbeh et al., 2021a,c; Ramadan et al., 2021).

According to the United Nations (UN), the COVID-19 pandemic has created the most prominent global disruption in education. Nearly, 1.6 billion learners in more than 190 countries have been affected by the COVID-19 pandemic. The closures of educational institutes have affected around 94% of the world's student population with more visible impacts in low- and middle-income countries (United Nations., 2020). Jordan was amongst the first countries in the Arab region to implement strict confinement measures in all sectors to control the spread of COVID-19 in the country (Al-Tammemi, 2020; Khatatbeh, 2020, 2021; Al-Tammemi et al., 2021). In the middle of March 2020, all universities were closed as a part of the pandemic response strategy in Jordan. Although there was no preparedness plan for the unprecedented transition to online distance education, the Jordanian government has invested extensive efforts through various ministries to make this emergency academic transition effective and efficient.

TABLE 1 Participants' characteristics (n = 17).

Variable	Category		Frequency count (n) - total
Age	Median = 20 years		
Gender	Female		9
	Male		8
Residence region[a]	Northern Jordan		5
	Central Jordan		8
	Southern Jordan		4
University	Public		10
	Private		7
Study program/discipline	Medical programs	Students' frequency count-subtotal	7
	Dentistry	1	
	Medicine	2	
	Medical laboratory sciences	1	
	Nursing	2	
	Pharmacy	1	
	Non-medical and sciences programs	Students' frequency count-subtotal	10
	Biology	1	
	Biotechnology	1	
	Childhood education	1	
	Engineering	1	
	Economics	1	
	Law	1	
	Literature and languages	1	
	Mathematics	1	
	Natural sciences	1	
	Psychology	1	
Study level	Bachelor		12
	Master		5
	Doctorate		0

[a]Jordan is administratively divided into three regions: Northern Jordan comprises four governorates including Irbid, Ajloun, Jerash, and Mafraq; Central Jordan comprises four governorates including Amman, Zarqa, Balqa', and Madaba; Southern Jordan comprises four governorates including Karak, Tafieleh, Ma'an, and Aqapa.

TABLE 2 Coding scheme with inclusion and exclusion criteria.

Theme	Definition of theme	Inclusion criteria	Exclusion criteria
Students' psychological response to the sudden transition in educational process	How the students reacted emotionally during the sudden transition process, including any coping mechanisms	Statements that describe various emotions and coping activities (if any) without limitations	N/A*
Students' digital preparedness, equality, and digital communication	Digital literacy and preparedness, forms of communication and perception of equality	Statements that report number of electronic devices used, digital platforms, and readiness	N/A
Students' and teachers' technical competencies and technostress	Competencies in using information and communication technology (ICT), and any related challenges	Statements that report issues related to technostress, and ICT related challenges	N/A
Student-student and student-teacher interpersonal communication	Various aspects of communication between students, and between students and their teachers	Statements that report challenges and/or opportunities in inter-personal communication	N/A
Quality and quantity of learning materials	Educational material provided to students, in terms of quantity and quality.	Statements that are related to the amount of proposed educational materials and their quality	N/A
Students' assignments, examinations, and non-reliable evaluation methods	Various methods of completing the required assignments and examinations. In addition to the utilized evaluation methods in terms of reliability and effectiveness.	Statements that describe any challenges related to reliable and effective students' academic assessment	N/A
Opportunities with positive impact of distance learning	The advantages of emergency remote education as a new experience	Statements that report opportunities to benefit from the positive aspects of such an experience in distance education	N/A

*N/A = not applicable.

Nevertheless, the higher education system in Jordan has an unpleasant history regarding online distance education, and even the equivalency process for many external distance/online degrees was and still is a significant challenge (Akour et al., 2020). Prior to the COVID-19 pandemic, the distance education strategy was not one of the priorities of the Jordanian higher education sector with around 25% or less of university courses were delivered remotely. Therefore, the abrupt transition from traditional face-to-face education to distance education in the Jordanian higher education institutions has created a new challenge for the students as well as the teachers. Our study found that the university students in Jordan have faced many impactful experiences while transiting from on-campus education to online distance one. Many of these experiences have negatively impacted the students similar to what was reported in prior quantitative studies in the country (Akour et al., 2020; Al-Balas et al., 2020; Al-Tammemi et al., 2020). Additionally, the literature shows more negative feedback within developing countries and the Arab region. The sudden switch to online distance education highlighted that this part of the world is not yet ready for this switch.

The overall aim of the current study was to get in-depth view about the lived experiences of university students in Jordan during the emergency academic transition to online learning amid the pandemic crisis. Presenting the voices and feelings of the students using their own words is expected to have a major impact on tackling the strengths and weaknesses of the implemented online education strategy in the country. Consequently, tackling various factors that impacted the students' lived experiences has paramount importance to enhance the current education strategy, by implementing improvements and creating opportunities for a more quality education.

As many students in our study stressed the points related to digital preparedness, equity, and technical challenges, their lived experiences were found to be consistent with what has been reported in previous studies. Some studies provided an insight into the additional inequalities introduced by the online education system. Most of the reported disadvantages included the financial ability to purchase the needed equipment, such as laptops or desktop computers, high-speed internet, or other tools (Al-Balas et al., 2020; Alsoud and Harasis, 2021; Ibrahim et al., 2021). Moreover, the ability to afford a separate and quiet place to study and attend lectures is related to many factors, such as the number of members in the household, home size, and socio-economic status; thus, providing rich students with more privilege (Alsoud and Harasis, 2021; Ibrahim et al., 2021). The former factors also introduce rural-urban inequality as

rural areas tend to be more crowded, with smaller houses and with lower access to the needed equipment and technological infrastructures (Alsoud and Harasis, 2021; Ibrahim et al., 2021).

The current study has many strengths which are shaped in the following facts (i) Implementing a qualitative approach which helped to gain a comprehensive understanding of the students' lived experiences and opinions, (ii) using a previously published theoretical model to support the framework of our qualitative approach, (iii) employing a maximum variation sampling to capture diversity in the students' opinions, (iv) using various techniques as suggested by Lincoln and Guba (1985); Nowell et al. (2017) to ensure the trustworthiness of qualitative approach, and lastly (v) following the COREQ.

Nevertheless, some limitations need to be acknowledged, including that the interview data represent self-reported states, thus, recall bias should be considered, and participants' body language could not be fully observed due to using a videoconferencing platform to conduct the interviews. Additionally, taking into consideration the nature of qualitative research, the results cannot be generalized to all students/target population, and due to conducting this research in a stressful period amidst the COVID-19 crisis, the students' answer might have been influenced by the psychological and socioeconomic impacts of the pandemic. Moreover, the small sample size – despite reaching data saturation, is considered one of the limitations in the current study. Lastly, as the study was advertised on social media, this may have resulted in missing the voices of students who were not regularly active on such platforms; thus, missing the advertisement.

The ongoing evolution in educational technology is significantly impacting learning resources, learning processes, and the academic performance and achievement of students (López-Belmonte et al., 2021). Taking into consideration the findings of the current study, many implications and recommendations can be drawn to support effective and efficient transition from traditional on-campus learning to distance or even hybrid learning technology. Some of which are: establishing clear policy and strategies to enhance a smooth implementation of distance learning in Jordanian universities, maintaining equality and quality education, targeting the weakness points provided by the students (e.g., poor internet connection, insufficient practical sessions/materials, etc.) with more realistic solutions based on piloted projects in distance learning, effective engagement of faculty staff in various trainings related to improvement of their technological competences. Additionally, decision-makers of the education sector in Jordan are advised to consider the psychological and socioeconomic factors of students in future policies and decisions regarding university education during a crisis or an emergency event. More dedicated efforts in terms of fair, reliable, and credible evaluation and monitoring systems should be also considered in such policies.

Conclusion

The COVID-19 pandemic has imposed a significant burden on university students in Jordan. The sudden transition to online distance education was challenging for most participants in our study. Although the degree of resilience and coping in crisis is inherently different between students, various entities under the jurisdiction of academic institutions and decision-makers are considered main contributing factors to the students' lived experiences amid the pandemic crisis. The battle against COVID-19 has been already exhaustive in terms of efforts and resources, therefore, better planning and more sustainable utilization of educational resources have paramount importance in contexts with limited resources.

Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author/s.

Ethics statement

The studies involving human participants were reviewed and approved by the Deanship of Scientific Research at the University of Jordan with a reference number (IRB# 310/2020/19). The patients/participants provided their written informed consent to participate in this study.

Author contributions

AA-T and HF: conceptualization and methodology. AA-T: supervision and writing—original draft preparation. AA-T, MK, and MB: data collection and data analysis. RN, CJ, DA, HA-M, MA, and HF: literature review. AA-T, RN, CJ, DA, MA, MK, MB, HA-M, and HF: writing—review and editing. All authors have read and approved the submitted manuscript.

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Conflict of interest

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

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.960660/full#supplementary-material

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Review on the teaching of programming and computational thinking in the world

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Recent studies suggest that computational thinking, composed of the skills of abstraction, decomposition, algorithmization, debugging, and problem-solving, is the fundamental skill for scientific, technological, and economic development for the twenty-first century. However, this diagnosis that is unveiled in rich countries remains nebulous for poor countries. The problem is that education in computational thinking is fundamental for countries to insert themselves in the international arena in an advantageous way and thus achieve the welfare goals for the population of each country. The objective of this research was to make a bibliographic review that shows the state of the art in the teaching of computer programming and computational thinking in the 5 continents. In the review, the advances in the countries of Europe, North America, Oceania, and Asia were observed, whereas in Latin America and Africa, the advances are still basic in some countries and non-existent in others. This review is based on Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA). The main search terms were "Computational thinking" and "Teaching computer programming." The search was performed in the ACM, Conference on Computational Thinking Education (Hong-Kong), Google Scholar, WOS, and SCOPUS databases, from October until December 2020, whose publication year was from 2016 onward. One of the main results found is that the teaching of computational thinking in England was implemented in schools in 2014; in Germany, it has been implemented since 2016 at a transversal level in universities; in South Korea, China, and Taiwan, it has been implemented since 2016. However, in Latin America and Africa governments, the subject is still not considered.

KEYWORDS

computational thinking, computer programming, algorithm, programming, computer science

Introduction

Contextualization

In the last decade, teaching of computational thinking skills in compulsory education is being developed in various countries around the world, which is a strategic decision

for technological development and for the acquisition of twenty-first century skills. In this rapidly advancing world, education professionals are subjected to new demands during the exercise of teaching, which has caused training institutions to permanently analyze their academic work, to make the necessary adjustments to their teacher training programs to respond to the new demands (Coppelli, 2018).

In this context, questions arise; Will it be necessary to include the teaching of computational thinking as a compulsory subject? Second, from which course should it be incorporated, how many hours per week would be necessary? Or would it be better to incorporate it as a development axis in existing subjects, such as technology education? Even the question arises whether it will be necessary to incorporate it in a transversal way, in all subjects? Then comes a second group of questions: Regarding teachers, are there teachers prepared to teach computational thinking, are there didactic strategies aimed at it, and also have evaluation instruments been developed to measure achievements at each educational level? All these questions and many others may arise when dealing with the issue of teaching computational thinking and the teaching of these skills in the educational system.

As for computational thinking, it encompasses a range of thinking skills specific to problem-solving, including abstraction, decomposition, debugging, pattern recognition, logic, and algorithm design, among other skills. But it is not only this because problem-solving skills also go beyond rote learning and procedural skills. Logical thinking involves analyzing situations to decide about an event. Algorithms are step-by-step procedures for solving problems, which are then codified in a programming language. It should be noted that computational programming is the natural scaffold for the acquisition of computational thinking skills, so its teaching from school is essential for future professionals to fully integrate it as mathematics, science, and language (Grover and Pea, 2018).

The implementation of computational thinking in school is already advancing in several countries, as in USA in December 2015 was signed the Federal Law entitled "Every Student Succeeds," which is responsible for public policies in this country. This law places computing on an equal footing with other academic disciplines, such as Mathematics, Geography, History, and Science (Brackmann et al., 2016). In January 2018, the Spanish Ministry of Education, Culture, and Sport published the report "Programming, robotics and computational thinking in the classroom," the document describes the current situation of programming, robotics, and computational thinking in the basic curriculum and different autonomous communities and several unofficial initiatives, led from companies, universities, or civil society. There are some questions to answer about it, such as integrating it, within the current disciplines or whether it is preferable for it to be an extracurricular activity (Adell-Segura et al., 2019).

Teaching of computer programming

Despite it is true that this review aims to study the teaching-learning of computer programming, it is also true that the concept of "Computational Thinking" has taken some prominence whenever the subject of computer programming is addressed. Nowadays, the world is incorporating the teaching of computer programming for elementary and high school students, to develop computational thinking skills, which go far beyond learning to program. Thus, the teaching of computational programming serves as a scaffold for the development of computational thinking skills, which are transferable to other areas of knowledge, and it means that they not only remain in computer science scholars, but also radiate into the whole area of science and technology (STEM), also including art (STEAM) and beyond (Rojas and García, 2020).

According to Wing (2006), computer science is the study of computation and asks himself, what can be computed and how to compute it? To have enough elements of judgment and to appropriate a definition, we will show several research that address the studies based on computational sciences, which orient their meanings based on their applicability. We can number some applications of computing such as internet of things, social networks, big data, artificial intelligence, robotics, video games, communications, smart phones, augmented reality, virtual reality, etc. The reality is that computer science is ubiquitous, so it is something to know, or at least a part of its applicability (Psycharis et al., 2020).

The contributions of computer science in education are very broad. Thus, universities around the world are revising their undergraduate computer science curricula, because of which they are changing their first course in computer science to cover fundamental concepts, not just programming. In addition, interest in computational thinking has grown beyond undergraduate education, with many focusing on incorporating computational thinking into education from kindergarten through K-12. As for sponsors, they include professional organizations, government, academia, and industry. Computer scientists know the value of thinking abstractly, thinking at multiple levels of abstraction, abstracting ideas to manage complexity, abstracting to scale, iteration, debugging, and software testing, among others (Wing, 2011).

For García (2018), we cannot abstract from the teaching of programming, but schools must take steps with our young people to operate in a virtual world, for which they must prepare in the language of this century, without which they will become digital illiterates. Therefore, the school should train the youth with the skills of computational thinking. So far, the energy has been directed at training users of existing computational tools.

Of course, this is insufficient, since what the present century demands is to acquire the skills of computational thinking, to live a new way of thinking and problem-solving. Therefore, instead of teaching students to be the users of a changing technology, they should be trained in the new paradigm of computational thinking, to be creators of new technologies (García, 2018).

According to Wing's (2006) definition, computational thinking has been supplemented as a generalized problem-solving approach applicable to a broad matrix of STEM and non-STEM fields. A formal definition is still an open topic of discussion in the literature, but in general, scholars agree that computational thinking skills include algorithmic thinking, navigating multiple levels of abstraction, decomposing problems into manageable pieces, and representing data. Computational thinking can be taught with or without the use of computers, but it is often operationalized through computer programming, as this makes the abstraction at the heart of computational thinking easier (Grover and Pea, 2018).

It should be noted that, with the research shown and speaking from experience, it could be safely said that computational thinking is the set of skills such as abstraction, decomposition, pattern recognition, algorithmization, debugging, and problem-solving, which could be extended to the skill of critical thinking. For the author, computational thinking is a new paradigm that expands the cognitive skills of students, in terms of making visible issues that until now are typical of computer technicians and professionals, but that undoubtedly will be a great contribution to the learning of science, mathematics, and many other areas of knowledge, where abstraction and the decomposition of problems, parallelism, and thinking at multiple levels provide the necessary contributions for students to learn from a different approach to the traditional one, especially modeling skills that allow the integration of all skills into a broad knowledge capable of integrating diverse cognitive skills.

General objective and research questions

The general objective was to make a bibliographic review that shows the state of the art in the teaching of computational programming and computational thinking in the 5 continents (see Figure 1).

It also suggests the possible lines of action that should be followed by the countries that are at the stage of evaluating the implementation of computational thinking.

Research questions:

What is computational thinking and how is it linked to computational programming?

Are there didactic strategies in the teaching of computational programming at school? And if so, what didactic strategies are used in the teaching of computer programming at school?

What is the international context in which the process of teaching computer programming is designed and implemented at different educational levels; primary, secondary, and tertiary?

Which are the pioneer countries in implementing the teaching of computer programming, what are they doing?

Which computational tools/programming languages are most used to provide the scaffolding toward the acquisition of computational thinking skills?

Method

Search terms and databases consulted

In the first instance, the trend of the investigated concepts (Computational Thinking and Computational Programming) was reviewed in Google trends (trends.google.es/trends), which showed a growing interest in investigating computational thinking from 2014 onward. This review is based on The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. International Journal of Surgery, 88, 105906 (Page et al., 2021).

The search terms were as follows:

- Primary search terms: "Computational thinking" and "Teaching computer programming."
- Secondary search terms: Teaching computational programming in elementary school, secondary school, tertiary/higher education, educational robotics, gamification, and didactics in computational programming.

A detailed search was conducted in the following databases since October until December 2020, whose year of publication was from 2016 onward, due to the accelerated obsolescence of the investigated subjects and associated technologies:

* ACM (Association for Computing Machinery) Digital Library.
* Google Scholar.
* WOS AND SCOPUS.
* Conference on Computational Thinking Education (Hong-Kong).

Selection of articles

The flow chart summarizing the searches in the various databases is below. It shows the articles eliminated and the reasons why (see Figure 2).

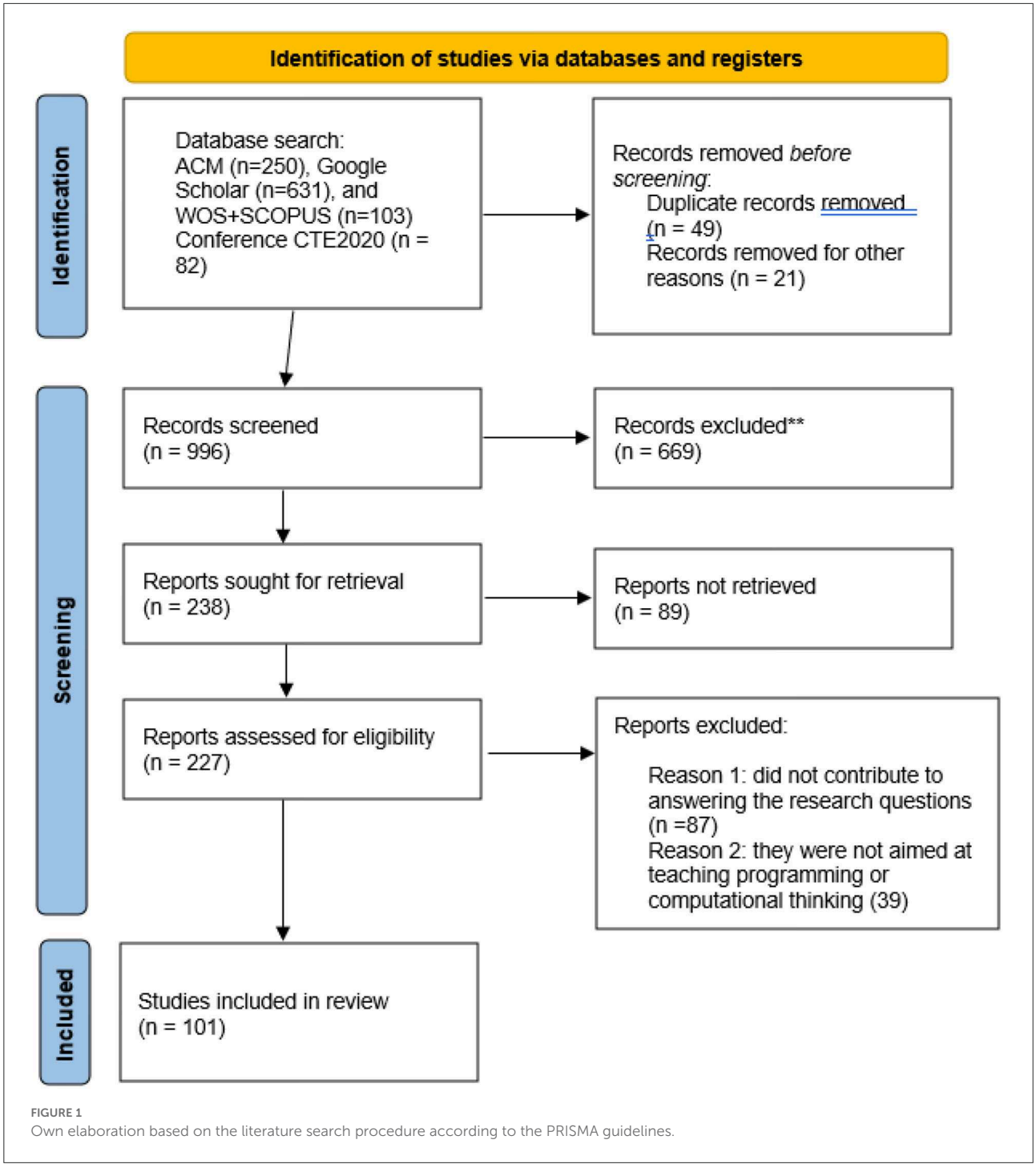

FIGURE 1
Own elaboration based on the literature search procedure according to the PRISMA guidelines.

In the ACM Digital Library, the use of the main terms together with all secondary search terms resulted in 251 articles. After eliminating by title, 60 publications were retained.

A Google Scholar search (combining all secondary search terms with computational thinking) yielded 631 articles. After filtering by title and eliminating unrelated articles, 96 publications were retained. In addition, 21 articles were found in WOS and SCOPUS.

In the publications of the Conference on Computational Thinking Education (Hong-Kong, 2020), which was held for the first time in 2017, many papers were found and an own categorization of computational thinking, which guide the

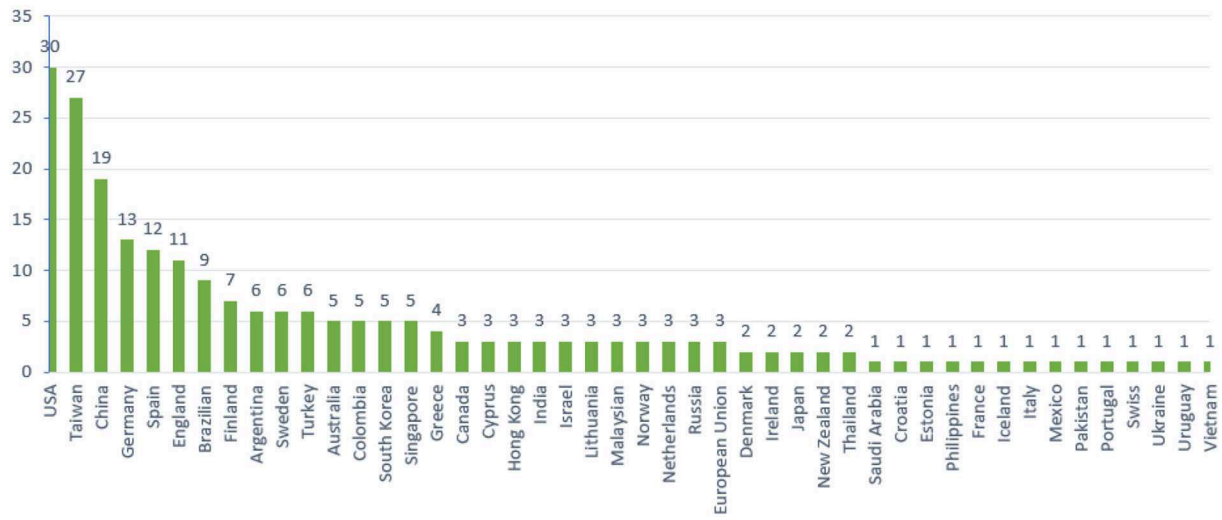

FIGURE 2
Number of paper per country.

search toward new horizons, from where in addition to the published papers were the references of each of them, so we proceeded to review most recent publications and those of greater interest, and thus, 82 publications were completed.

The inclusion and exclusion criteria were developed as recommended in the systematic review guidelines.

The texts considered have the following characteristics:

* Directly answered one or more research questions.
* Were related to the teaching of computer programming in educational institutions.

Studies were excluded if they:

* Were in a book format or gray literature (opinion articles, technical reports, blogs, presentations, etc.).
* Did not answer any research question.
* Other exclusion criteria used, was to ask the following questions:
- How well does the evaluation address its original objectives and purposes?
- How well was the data collection conducted?
- How clear and coherent is the report?

After these steps, which consisted of reading the abstracts and conclusions, and eliminating articles if they did not comply with the above criteria, 101 articles were selected for review. Regarding the year of publication of the articles reviewed, it is highlighted that 19% are from 2018, 40% correspond to the publications from 2019, 22% are the publications from 2020, and 5% are the publications from 2021.

Results: The main research

Contextualization

Undoubtedly, the teaching of computer programming lacks a didactic that guides it and that doses the contents in smaller units, disaggregating the complexity, to make learning more fluid for the students. In the computing field, it is like another side of teaching, which does not include didactic elements from other STEM areas, and runs on its own track, where those who teach do not have pedagogical training and teach using the same method as they learned, which generates a vicious circle contrary to didactics as it happens in mathematics, science, and other areas of learning. The teaching of computer programming is fundamental to acquire the skills of computational thinking, which opens new opportunities to learning with the skills of abstraction, problem disaggregation, algorithmization, parallel task processing, debugging, and pattern recognition, among others.

Thus, in this review, we will seek to answer the research questions, to guide what is being done in the field, or to define what is intended to be done in the various countries. It should be noted that not all the publications were written in English, so the translation from Chinese, Russian, Korean, and German, among others, was needed. However, the common denominator found was that the teaching of computational thinking is the key skill for the twenty-first century, that it should be taught from an early period of time, that its skills are transferable to other areas of knowledge, and that computer programming is the natural scaffolding to achieve this goal.

The research questions to which answers were sought were the following: What is computational thinking and how is it linked to programming? Are there didactic strategies in the teaching of computer programming at school? And if they exist, what didactic strategies are used in teaching computer programming at school? What is the international context in which the process of teaching computer programming is designed and implemented at different educational levels; primary, secondary, and tertiary? What are the pioneer countries in the implementation of teaching computer programming, what are they doing? What computational tools or programming languages are the most used to provide the scaffolding toward the acquisition of the skills of computational thinking?

By obtaining the results, several ways of facing the problem of the lack of didactic strategies in the teaching of computer programming were found. Some of them resort to the use of games, others to educational robotics, metaphors, etc., but none of them proposes a properly developed didactic, which is applicable to all contexts and levels of teaching, rather they are trials and errors. It stands out to the general rule, the 10 didactic principles of Brown and Wilson (2018), which create a kind of algorithm for teaching programming, which is perhaps the path that should be followed. In this sense, it is left to the reader to acquire the necessary elements of judgment, such as validating one or another attempt to shape didactics of computational programming, just as didactics of mathematics and science have.

Computational thinking—Research and concepts

Computational thinking is unquestionably the skill that young people of the twenty-first century must acquire, and computational programming seems the logical way to achieve it, since making a computer program confronts the student with problem-solving, abstraction, task sequencing or task algorithmization, parallelism, and code debugging. In 2018, Ching et al. published the research, in which he begins by positing that computer programming should be taught for children of all ages. Here, in the research conducted, computational thinking is considered as a broad problem-solving framework involving problem-solving skills, processes, and approaches, and "programming" as a key practice to support and cultivate the cognitive tasks involved in computational thinking (Ching et al., 2018).

The following research works computational thinking from a different perspective, and here, it seeks to teach the same computational thinking skills, but without the need for a computer laboratory. In 2017, Brackmann's et al. research set out to develop computational thinking skills through unplugged activities in elementary school, for which they conducted a quasi-experiment with 5th and 6th graders from two public elementary schools in Madrid, which has 73 students aged between 10 and 12 years. The unplugged approach is important for schools that do not have technological resources, internet connections, or even electricity. Regarding this, there is a lack of research showing the effectiveness of unplugged activities in the development of computational thinking skills, especially in elementary schools (Brackmann et al., 2017).

A key issue in the development of computational thinking is the measurement of such skills, and thus, some design and validation guidelines for computational thinking content have been developed (González, 2015). Developing computational thinking of young children with educational robotics allows an interaction effect between gender and scaffolding strategy (Angeli and Valanides, 2020). In the same sense, there are successful experiences of teaching programming and robotics in elementary and middle school education (Gómez et al., 2019). Developing students' computational thinking with a poly-disciplinary approach becomes fundamental for the student group, due to the diversity and multiple approaches from different professions (Klunnikova et al., 2020). In summary, programming expertise promotes greater STEM motivation among all the students and with a focus on first-year girls and boys (Master et al., 2017).

Other publications show a series of research that deepen the development of computational thinking and programming, of which stand out the methodological proposal based on metaphors to teach programming to children (Pérez et al., 2018), the development of programming skills in engineering education through problem-based game projects with Scratch (Topalli and Cagiltay, 2018), the introduction to computer science as a part of the general education curriculum for the whole university (Khenner, 2019), toward the use of computational models in learning physical computing (hardware) (Seow et al., 2020), the comparison of learning behaviors of third-year elementary students and integrate robots and computational thinking board game in Singapore and Taiwan (Liang and Hsu, 2020), and the alignment of the framework in STEM classrooms infused with computational thinking (Bain et al., 2020).

In the same vein as the previous paragraph, a study about changing the way a generation thinks by teaching computational thinking through programming is also shown that it is a giant challenge, no doubt (Buitrago et al., 2017). Other authors focus on education in computational thinking, the problems, and challenges it holds (Angeli and Giannakos, 2020). In a following study, there is an analysis of response theory to the element of sequencing algorithms and programming concepts (da Cruz Alves et al., 2020). And finally, research about computational thinking skills and their impact on the achievements of the Trends in International Mathematics and Science Study (TIMSS) test, a study that looks in depth at the scope of such measurement, which will set the tone in the educational development of countries (Alyahya and Alotaibi, 2019).

The results will be shown in the following two categories

- Lines of research in applied programming education.
    - * Gamification.
    - * Educational robotics.
- Pedagogical and didactic elements.
    - * Pedagogical and didactic practices.
    - * Didactic methods in Computer Programming.
        - ◦ Learning programming like learning a second language.
        - ◦ Metaphors and building blocks for teaching programming.
        - ◦ Ten principles for teaching programming, by Brown & Wilson.

Now regarding the countries that publish, these investigations are mainly found in the continents, Europe, Asia, and North America. With less participation are some Latin American countries, such as Colombia, Brazil, and Argentina. The following graph shows the number of articles reviewed by country:

Lines of research in programming education applied

The following are some of the research lines associated with this work, such as gamification and educational robotics, which provide guidance on the teaching of computer programming in these areas.

Gamification: Teaching using games. Teaching by games in the field of computational thinking covers a range of possibilities, ranging from the design, construction, and use of games to the production and marketing of video games. Thus, there are experiences of the use of digital games in storytelling, learning mathematics, history, etc. Children learn better history if they play Age of Empires, personal reading books are more attractive if they are developed in animated environments, and mathematics is fun if there is an interaction with numbers and they are contextualized in a real environment, etc. In this regard, de Paula et al. published in 2018 an article entitled "Playing Beowulf," featuring a game produced by two 14-year-olds, "Playing Beowulf," which is a collaboration with teenagers from the British library (de Paula et al., 2018).

In the United States, researchers published an article in 2017, which presents an empirical study that provides evidence that a mathematical educational game can help with superior learning opportunities, as well as being more engaging. The "Decimal Point" game is a single-player game and is based on an amusement park metaphor and is aimed at high school students. The game is called "Decimal Point: the fantastic and fabulous world of fractional fun." In the game, the student travels sequentially to different theme areas (Haunted House, Wild West, Space Adventure, Amusement Park), playing a variety of mini games within each theme area aimed at learning decimals. Student progress is tracked by tracking the park and students are visually cued to the next game they will play (McLaren et al., 2017).

In the same vein, researchers Zhou and Hsu from National Taiwan University published in 2020, a study that aimed to integrate the computational thinking board game with robots, so that students put computational thinking skill into practice when completing the board game tasks by controlling the action of robots. The participants were sixth-grade students in Singapore. In total, two students divided into a team collaborated with each other, competed with the other team composed of two other students. The research used Robots City board games to enable the students to cultivate the concept of computational thinking through game-based learning and use cell phone applications to control robot behavior with programmed logic for analysis (Zhou and Hsu, 2020).

Finally, there are other research such as, Fotaris et al. (2016), with conducting an empirical study of the application of gamification techniques in a computer programming class, where it uses a leaderboard as motivation for players. Daungcharone et al. (2019) present learning the C programming language based on the mobile games to improve students' learning. Also, Pellas and Vosinakis (2018) show the effect of simulation games in learning computer programming on the learning performance of high school students by assessing computational problem-solving strategies. There is a wide range of applications of computer games to motivate and enhance learning, not only in the areas of computer science, but also in different areas (Wing, 2011).

Educational robotics. An educational robotics paper presented at the "International Conference on Computational Thinking Education 2020" in Hong Kong, which explored the learning behaviors of sixth-grade students using educational robots in English oral interaction learning units, in which a smart phone application was provided to control the action of the robots and ask students to orally interact with their peers to put learning sentences into practice. Then, the foreign language interactive behaviors were recorded and observed during the collaborative learning task period. The participants were 18 English foreign language learners, aged between 11 and 12 years (Kong et al., 2020).

It should be noted that multimedia environment can reduce students' anxiety and provide a less stressful classroom environment. In addition, multimedia tools enable English teachers to help the students improve their English performance and reduce language anxiety (Huang and Hwang, 2013 in

Kong et al., 2020). When students begin to feel confident in a foreign language classroom, they will naturally start speaking. Ultimately, all foreign language teachers need to motivate learners, encourage them to speak, and allow them to make mistakes freely (Atas, 2015; in Kong et al., 2020). Experimental results show that, in the learning process, with the help of educational robots, students speak English as a very common action to give commands to the robot. To complete the goal of the class, it is possible to interact with students in spoken English (Kong et al., 2020).

In another research at the Norwegian University of Science and Technology, a paper was conducted that deals with children's collaboration and participation, and their attitudes in game programming and educational robotics. The goal of the work was to investigate how collaboration and engagement moderate children's attitudes about programming activities. For this purpose, a study was designed with 44 children aged between 8 and 17 years, who participated in a full-day computer programming activity. Their participation and collaboration during the activity was measured by recording their gaze and attitudes regarding their learning, enjoyment, teamwork, and intention using post-activity survey instruments. Behavior was found to moderate the relationship among intention to learn, attitude toward teamwork, enjoyment, and observed learning (Sharma et al., 2019).

Also, authors Lee and Low (2020) conducted the implementation of a computational thinking curriculum with robotic programming activities. In addition, Cheng et al. (2018) investigated on the essential applications of educational robot through a requirements analysis from the perspective of experts, researchers, and instructors. Regarding SRA (Sense, Reasoning, Action) programming, authors Fanchamps et al. (2020) investigated the influence of SRA programming on algorithmic thinking using robotics. They also investigated the effects of using cell phone software to control educational robots with third-grade elementary school students (Yi and Ting, 2020, in Kong et al., 2020). In addition, Paucar-Curasma et al. (2022) conducted a study with a group of students aged 6–13 years in Peru, which was developed during 4 weeks, and applied computational thinking assessments applying the concepts of sequences, cycles, parallelism, conditionals, operators, and data manipulation, which allowed an appropriation of computational thinking skills by the participants in an optimal way (Paucar-Curasma et al., 2022). Finally, researchers Souza et al. (2019) analyzed the effect of computational thinking in mathematics through educational robotics.

Pedagogical and didactic elements

From the articles and reports selected and reviewed, all agree that computational thinking is the essential skill for education and industry in the twenty-first century, as it provides complex cognitive skills such as abstraction, decomposition, problem-solving, and algorithmic thinking, skills that are not only necessary for the scientific and technological development of humanity, but also for the preparation for work and the challenges posed by the automation of work and the loss of jobs as a result of robotization and artificial intelligence. With the above in mind, the challenge for governments is to prepare future generations for this complex world ahead; however, countries that have implemented educational reforms have found themselves with a shortage of teachers trained in the areas of computer science (Bocconi et al., 2016).

Pedagogical and didactic practices

Japanese researchers conducted research on pedagogical transformation based on computational design and thinking. Now, that technology has become ubiquitous, and it is more appropriate to discuss transformative pedagogy where technology is no longer considered a tool, but part of who we are. We do not believe that there is a strong basis for claiming that the integration of technology was the game changer, for our students working on extensive and complex robot programming tasks; rather, it was the design of teaching and learning in practice that made the real difference. A key implication for heutagogical (self-determined learning) practice that follows is that technology must build on a solid understanding of key concepts in teaching and learning, not the other way around (Vallance and Towndrow, 2016).

In turn, Chinese researchers from Hainan University investigated on a model of blended learning and the cultivation of innovative talent, whose mechanism is based on computational thinking. Computational thinking includes computational thinking and integration with the social and natural environment, including evolutionary thinking in general computing environments, alternatively promoting and co-evolving problems. In the future, non-computer science professionals can use computer science means for innovation in various disciplines. They can also develop support for various disciplines of research and innovation of new media of digital technology. Computational thinking can effectively help non-computer science professionals to bridge the gap between learning and training with common computing tools for future professionals (Zhang et al., 2019).

Didactic methods in computer programming general. In 2018, the book "Content and Skills of Computer Science" was published in Germany by the university press of the University of Potsdam, which makes a tour on what should be learned in computer science by the students of higher education of all careers, which receives the contributions of different academic teams of the German university world, to contribute collaboratively to lay the foundations of the skills that professionals

of the twenty-first century should possess. On this, some of the papers included in the publication are highlighted (Bergner et al., 2018).

In the publication, it was found that the central topics were algorithms, computer programming, and data representation, but also elementary technical concepts of computers and the internet. Courses also appeared that touched on traditional topics, on social implications, privacy, and the role of computer science in society. Regarding programming environments, programming systems were used professionally in most of the courses. Among the recommendations, it is indicated that it would be better to design courses focused on the specialties in which they are taught, since this would enhance the students' learning and applicability in subsequent subjects to be taken, thus better achieving the objectives of metacognition.

Computational thinking develops naturally in higher education, as shown by the research seen, which for reasons of space, it is not possible to show them in this section. The research deals with diverse topics, such as augmented reality for STEM learning; a computational thinking curriculum framework for lower sixth with implications for teachers' knowledge; computer science as a core competency for teachers in other disciplines; trainee teachers' views on computational thinking—STEM vs. non-STEM teachers; technology-enhanced learning in higher education; motivations, engagement, and academic performance; a study between Finland, mainland China, Singapore, Taiwan, and South Korea, comparing teachers' perceptions and preparedness to teach programming skills (Wu et al., 2020).

Learning programming using learning a second language methods. The introductory course in computer programming is first and foremost a language course, since teaching a language is already a component of the introductory programming course. The issue has been the pedagogical approach to teaching the linguistic aspects of the course, a teaching structure long abandoned for natural languages modeled after a linguistics approach (based on rules of grammar instruction), rather than incorporating principles of second language acquisition. In the twenty-first century, there are virtually no natural language classrooms using the prescriptive linguistics approach, yet it remains the universal teaching model for learning a programming language (Portnoff, 2018).

The absence of grammatical rules for learning programming causes students has a conceptual pedagogical gap to bridge on their own, even though instructors expect to solve problems using logic mediated by a programming language, in that most struggle to express basic fluency. Even those talented enough to get their programs to run and function correctly still compose inadequately structured programs well into their first year. The specific difficulties in learning a programming language coincide with the difficulties of learning a second natural language. The complications stem largely from the small number of control structures that programming languages employ, even though they are adaptive and are semantically broad (Portnoff, 2018).

Metaphors and blocks for teaching programming. Pérez et al. (2018) proposed using metaphors such as recipe/program, pantry/memory, and boxes/variables. They also illustrate the possibility of applying these metaphors to any resource available to the teacher. In total, four step-by-step scripts are provided on how to use metaphors in class, with the opinions of 62 children (enrolled in fourth, fifth, and sixth grades of Spanish Primary Education, ages 9–11) and their teacher. This proposal has been validated with 62 Spanish children, who found the metaphors useful in more than 65% of the cases. The students were able to understand the metaphors (<30% of the students found the metaphors difficult) and <10% of the students did not want to use the metaphors. The teacher was also asked to evaluate and validate the methodology (Pérez et al., 2020). In this same line in 2021, a research by Jiménez Toledo et al. (2021) published a study entitled "Discovery Model Based on Analogies for Teaching Computer Programming" through which he applied a discovery model that allowed the extraction of patterns, textual and linguistic analysis, in addition to the use of analogies for teaching the fundamental ideas of computer programming, which allowed to achieve better learning in students (Jiménez Toledo et al., 2021).

In another case, 20 years ago, AgentSheets combined four possibilities to create an early form of block scheduling. After initially focusing on syntactic possibilities, AgentSheets in computer science education, new approaches have been experimented with to go beyond syntax to address semantic and pragmatic obstacles. Thus, three approaches are described: (1) contextualized explanations to support understanding, (2) conversational programming to proactively assist and predict the future, and (3) live palettes to make programming more unpredictable. The block scheduling community has been concerned about the syntactic possibilities of the scheduling environment. It is time to shift research agendas toward systematically exploring the semantic and pragmatic possibilities of block programming (Repenning, 2017).

Ten principles for teaching programming, by Brown and Wilson (2018). Neil Brown is a researcher at King's College London University in England, and Greg Wilson belongs to the computer training organization DataCamp in Toronto, Canada, which after arduous bibliometric research and the experience accumulated in the development of their academic functions, offer ten principles for learning to program.

Principle 1: Remember that there is no such thing as the programming knowledge gene.

Computer programming skills are not innate, but rather a learned skill that can be acquired and improved with practice.

Principle 2: Use the help of your peers.

One-on-one tutoring is perhaps the ideal form of teaching, a teacher's full attention can be focused on one student, and they can fully customize their teaching for that person and tailor individual feedback and corrections based on a two-way dialog with them.

Principle 3: Use live coding.

Instructors should create programs in front of their students. This is most effective for several reasons: (1) It allows instructors to better answer "what if?" questions. Live coding allows instructors to follow the interests of their and (2) it facilitates unintended knowledge transfer.

Principle 4: Encourage students make predictions.

When instructors use live coding, they usually run the program several times during its development to show what it does. The key to making demonstrations more effective is to have students predict the outcome of the demonstration before running it.

Principle 5: Use pair programming.

Pair programming is a software development practice in which two programmers share a computer. One individual (called the driver) writes, whereas the other (called the navigator) offers comments and suggestions. The two switch roles 2–3 times per hour.

Principle 6: Use solved examples with labeled objectives.

A good way to guide students in building programs is to use solved examples: step-by-step guides that show how to solve an existing problem.

Principle 7: Stay in one language.

A principle that applies in all areas of education is that transfer only comes with mastery of a programming language.

Principle 8: Use authentic tasks.

Learners find authentic tasks more engaging than abstract examples.

Principle 9: Remember that freshmen are not experts.

Freshmen are taking their first steps in learning programming, so initially confront them with small problems, broken down into chunks.

Principle 10: Do not just code.

Faced with the challenges of learning syntax, semantics, algorithms, and design, examples that seem small to instructors can easily overwhelm beginners.

Discussion and implementation of programming education

For this author, as a computer professional and educator, most of the conclusions are shared; however, with respect to the authors who state that programming could disappear, I consider that it is like saying that the use of the wheel could disappear because of the invention of airplanes. It is clear that advances in artificial intelligence and code generators such as CSS3 Generator, Colorzilla Gradients, Genexus, among others, have been and will continue to be a great contribution in software development, but computer programming is something fundamental in the formation of computational thinking skills, such as addition, subtraction, and multiplication, as it is for elementary school students. I agree that the focus should go beyond programming, since computer programming is a tool to move toward computational thinking, and incidentally allows future generations to have the ability to be creators of technology and not just users of it.

Undoubtedly, the implementation of the teaching of computational thinking in the various countries of the world demands a lot of resources, creativity, knowledge, and will of governments to generate policies that open the way for the training of today's students to become professionals that will make them competitive and capable enough to perform their jobs in the twenty-first century. In the area of the implementation of the teaching of computational thinking, this is where the playing field is most uneven worldwide. There are countries in which all schools are equipped with computers, such as Australia, England, Germany, Japan, and New Zealand, among others, and other countries in which there is a significant percentage of schools that do not have such infrastructure, as in Latin American countries, and other countries that have a percentage of schools that do not even have electricity, as in the case of India and Africa.

Main considerations

This review discusses the concept of computational thinking, a term that finds support in the skills of abstraction, decomposition, sequencing, algorithmization, debugging, and problem-solving skills. In the literature, computational thinking is mentioned as the skill of the twenty-first century, and computational programming as the natural scaffolding to move toward the incorporation of computational thinking as an active problem-solving skill. In addition, it is noted that these types of skills have already been incorporated in international tests such as Trends in International Mathematics and Science Study (TIMSS), which allows measuring the trend of countries in mathematics and science skills. In this sense, a research that talks about computational thinking skills and its impact on TIMSS achievement looks in depth at the scopes of such measurement, which will set the tone in the educational development of countries (Alyahya and Alotaibi, 2019).

For Grgurina (2021) in her work entitled "Getting the Picture: Modeling and Simulation in Secondary Computer Science Education," computational thinking includes the skill of modeling, a skill that is at a higher level of complexity than problem-solving. Thus, computational thinking includes formulating problems, so that it is feasible to solve them with a computer, organizing and analyzing data logically, representing data through models, and automating solutions through algorithmization, which includes abstractions and

parallelism. Thus, looking toward student training, these skills support and improve attitudes such as: confidence in dealing with complexity, persistence in working with difficult problems, tolerance of ambiguity, the ability to deal with open problems, and the ability to work with others to achieve a common goal and communicate it. Thus, for example, in two-schema modeling, students have to construct two schemas and combine them: a schema consisting of the situation to be modeled and the schema of the means (mathematical, computer, scientific, everyday life, etc.) that can be used in the construction of an understandable model representing the situation to be modeled.

Grgurina describes computational thinking in terms of its main concepts, such as: data collection, data analysis, data representation, problem decomposition, abstraction, algorithms and procedures, automation, simulation, and parallelization (CSTA Computational Thinking Task Force, 2011; in Grgurina, 2021). The definition of computational thinking is complemented by the Carnegie Mellon Center for Computational Thinking (CMCCT), which states that it consists of three fundamental aspects: abstraction, modeling, and algorithmic thinking (Carnegie Mellon Center for Computational Thinking, 2010; in Grgurina, 2021).

In the review made by Shute et al. (2017), entitled "demystifying computational thinking," he addresses the concept as the set of skills of decomposition, abstraction, algorithm design, debugging, iteration, and generalization, understood as necessary skills for problem-solving. Regarding computational thinking and programming, they are analyzed at the same level; however, it does not consider that computational programming through teaching allows acquiring computational thinking skills, since it is necessary to abstract and decompose a problem before coding a program, and also, depending on the complexity, it will be necessary to abstract at several levels, and once programmed, debugging and checking that what is done does what it should solve will be necessary, thus incorporating computational thinking step by step. Regarding the bibliography consulted, most of it is observed between 2011 and 2015, so what is said there has been changing, leaving some conclusions, rather obsolete.

It is highlighted in Shute Shute et al. (2017), a research developed, in which a scale was created to measure computational thinking (Román-González et al., 2017; in Shute et al., 2017), which includes a 28-item scale and takes about 45 min to complete. It focuses on programming concepts, such as directions and sequences, loops, conditionals, and simple functions. In addition, there is the taxonomy created that categorizes the different levels showing how lesson plans can be designed. The proposed taxonomy proposes the following main categories, from which subcategories are derived, to guide future computational thinking assessment designs:

(a) Data practice; which is composed of data collection, data creation, data manipulation, data analysis, and data visualization,
(b) Modeling and simulation, which is composed of the subcategories; conceptual understanding, testing solutions, model evaluation, model design, and model building,
(c) Computational problem-solving, which is composed of solution preparation, programming, tool selection, solution evaluation, solution development, abstraction, and debugging,
(d) Systems thinking, which is composed of systematic investigation, understanding the relationships between components, multilevel thinking, communication, and system management.

In the author's opinion, this seems to be a significant contribution that goes in the right direction, since it allows addressing in an orderly manner each of the categories necessary to learn in computer science, when it is necessary to acquire the skills of computational thinking.

Moreno-León et al. (2018) worked on a review on computational thinking as a universal skill, in which they conclude several things to highlight:

- That the focus should not be placed exclusively on programming, but on the skills that are developed through learning to code, specifically computational thinking skills,
- The most effective way to train these computational thinking skills is through programming,
- It is possible that in the future new and more efficient mechanisms for developing these skills in students will flourish.
- There are even authors who argue that programming could disappear in a few years due to the advances in artificial intelligence.
- Consequently, we argue that the metaphor for presenting this movement to the educational community should shift toward computational thinking as a universal skill that can foster the learning of subjects and skills across the elementary and middle school curriculum.

When the most advanced countries in this area are investigated, European countries appear in the first line, or rather the European Union, a conglomerate of countries that advance at an even pace in various areas and especially in technology and implementation of educational systems that allow them to be at the forefront in future generations. Thus, the case of Ireland stands out, just to cite one example, the case of England, which have been advancing very fast in the implementation of the teaching of computational thinking in school. However, progress has also been observed in Latin American countries, such is the case of a study conducted by researchers at the Universidad del Cauca Colombia, where

Cruz et al. (2013) and their team published a study entitled "ChildProgramming Process: A Software Development Model for Kids," which was aimed at training children at an early age (8–10 years old) with the concepts and skills of software creation (agile methodologies), which allowed fostering teamwork and introducing computational thinking skills.

In 2017, researchers Lockwood and Mooney from Maynooth University, Ireland, asked a fundamental question about computational thinking: computational thinking in education, where does it fit? It should be noted, that in Ireland, computer science is not yet an assessed subject at state level, such as mathematics, language, or science. Although steps have been taken to include it, so far, all that is available to the students in the curriculum is a short course in programming. While programming is a very useful skill and one that can be beneficial to students in a wide variety of careers, it is not the only part of computer science that is of interest to consider. Although scholars have not been able to agree on a universal definition, according to Wing (2006), she gives two visions that define computational thinking, which are (a) computational thinking will be fundamental to new discoveries in all fields of endeavor, and (b) it will be an integral part of early childhood education (Lockwood and Mooney, 2017).

Furthermore, it should be noted to say the authors, who thinking computationally, is of enormous benefit to all disciplines. In Ireland, researchers in the Department of Computer Science at Maynooth University, designed the PACT program (PACT is an acronym for Programming Algorithms = Computational Thinking). The goal was to introduce computer science to Irish high school students and teachers through programming and algorithms, with the idea of improving computational thinking skills in participating students. Now in its fourth year, the PACT program has been delivered in over 60 schools and to over 1,000 students. With the introduction of programming into the curriculum and the call from administrators and governments to include more computer science content in schools (Lockwood and Mooney, 2017).

In 2016, the European Commission, specifically the Joint Research Center (JRC) for policy reporting, published the paper "Developing computational thinking in compulsory education—Implications for policy and practice," which seeks to shape the implementation of computational thinking in compulsory education. The document points out that, in the recent years, computational thinking, which includes the concepts of coding, programming, algorithmic thinking, among others, has been promoted as skills that are fundamental to everyone like numeracy and literacy. At this point, the questions arise: how can we define computational thinking as a key twenty-first century skill for schoolchildren; what are the central features of computational thinking and its relationship with programming in compulsory education; how can teachers be trained to effectively integrate computational thinking into their teaching practice? (Bocconi et al., 2016).

With respect to the integration of computational thinking in compulsory education, four important areas emerge for policy makers and stakeholders to focus on: consolidated understanding of computational thinking, comprehensive integration, systemic deployment, and policy support. A resurgence in the integration of computational thinking and, more broadly, computer science into compulsory education is evident, as indicated by the recent wave of curriculum reforms. In total, eleven countries in Europe have recently completed a reform process that includes computational thinking and related concepts. Another seven are currently planning to introduce computational thinking in compulsory education. In addition, seven other countries are integrating computational thinking based on their long tradition in computer science education, mainly in upper secondary schools. Some of them are expanding computer science education to include primary and lower secondary levels (Bocconi et al., 2016).

In 2013, the document "Computing programmes of study: key stages 1 and 2 National curriculum in England" was published in England by the Department for Education for its curriculum. The document states that a high-quality computational thinking education prepares students to use computational thinking and creativity to understand and change the world. Computer science has deep links with mathematics, science, design, and technology and provides information about natural and artificial systems. The core of computer science is computer science, in which students are taught the principles of information management and computation, how digital systems work, and how to use this knowledge through programming. Based on this knowledge, students are equipped to use information technology to create programs and a variety of applications (Radin and Hawley, 2013).

In 2017, the education system in England, according to evidence, shows that computer science education in the UK is fragmented and fragile. Its future development and sustainability depends on swift and coordinated action by governments, industry, and non-profit organizations. Neglecting opportunities to act could damage both the education of future generations and economic prosperity as a nation. The broad subject of computer science, which covers the three vital areas of computing, has become compulsory in schools in England for ages 5–16. Students aged 5–14 have computer science lessons 1 h per week, and some schools take the opportunity to teach computer science within other subjects. However, most teachers are teaching an unfamiliar school subject without adequate support. Moreover, they may be the only teacher in their school with this task. Governments need to address a growing shortage of computer science teachers (Calderon et al., 2017).

On the other hand, Asia has also been given the importance that the implementation of teaching computational thinking in

school should have. An example of this is the progress made in South Korea, China, and Japan, among others. The case of Japan, which, although it is a technologized country with 99% robotized factories in the 1980s, encounters the same problems as all countries in terms of teaching computer programming in schools: the shortage of teachers to teach this subject, in addition to the lack of training in science, In other words, there are few teachers and these few are not always well-trained to teach programming, which generates the second floor for students to achieve the skills of computational thinking. In Japan, the teaching of computer programming in schools was implemented in April 2020, and the curriculum requires them to teach it in a playful way, which further complicates Japanese teachers due to the lack of research in the field and the absence of didactics in the teaching of programming (Gougeon and Cross, 2021).

Meanwhile, in South Korea, although computational thinking education is still in its early stages of nationwide implementation, there has been some research evidence supporting the effectiveness of learning programming skills and related computational thinking skills. Computational thinking in K-12 contexts, education has been conducted in the areas of (a) innovating specific pedagogical approaches to computational thinking, (b) developing assessment tools to measure students' computational thinking knowledge, skills, and attitudes, (c) expanding coding education in physical computing and maker education, and (d) training teachers in computational thinking skills. Large-scale research revealed that students, teachers, and parents have positive perceptions about the needs and effectiveness of software education in schools (So et al., 2020).

A very remarkable case is India, a country with many inhabitants, with multiple deficiencies in infrastructure, and education, in addition to a linguistic diversity, within all these difficulties has been proposed to implement computational thinking, not only with the idea of leaving and improve the economic conditions of its inhabitants, but as a tool based on the skills that will allow it to develop in the XXI century with the advantage that its population is knowledgeable about new technologies, and thus provide more job opportunities anywhere in the world.

The National Computer Science Policy for school education in India advocates the development of a curriculum model that would include knowledge enhancement and generic skill development, focusing on digital literacy. The computer science education that has been introduced in urban sectors in India focuses mainly on digital literacy and some computer programming. The implementation of computer science in the curriculum has not been easy and has had to go through several challenges. According to the government reports, India has more than 1.6 million schools offering K-12 education to 300 million students. The problem is compounded by the fact that education in the country is administered by two national boards of education, with each of India's 29 states having its own board of education! While the common language of instruction is English in urban areas, 70% of the population resides in rural areas where education is conducted in their own local language (Shah, 2019).

To prepare the students to creatively engage in the digital age, CSpathshala proposes an activity-based disconnected computational thinking curriculum for primary and secondary schools. The computational thinking curriculum is highlighted: teaching computation without computers, community-created teaching materials: 200 lessons, no cost to schools, subset of teaching materials translated into Gujarati, Hindi, and Marathi (dialects in India), 30,000 schools in Tamil Nadu learn computational thinking as part of the math curriculum. This includes 425 residential welfare schools, conducting 90 awareness workshops and training programs, at no cost to the schools, 5,400 volunteer participants from 2,650 institutions. With this plan, a light is seen in learning computational thinking skills, which though seems big, India is bigger with more than 1.4 billion population, but the growth of CSpathshala (https://cspathshala.org/) is spiraling exponentially (Shah, 2019).

Undoubtedly, other countries are also doing the same, as seen in the publications of Russia, China, Taiwan, Canada, the United States, Spain, Brazil, and Colombia, among others. Even smaller countries such as Chile in Latin America, which more timidly, only implemented elective courses in the third and fourth years of secondary school as a first step in the implementation of the teaching of computational thinking in school. In Chile, although there is no decisive support from the State in this area, the Kodea Foundation of Chile has created a curriculum with didactic material from first grade to fourth grade, which allows schools to have free access to everything necessary to incorporate computational thinking at school (www.ideodigiltal.cl).

Comments on other reviews considered

In 2016, Brackmann et al. conducted a review on computational thinking entitled "Computational thinking: Panorama of the Americas" in which he reflects on the impact of computers in the life of human beings, whose technology advances exponentially, a pace that unfortunately schools cannot follow, or at least cannot follow closely, since the development of the economy around technology encourages its development, and for schools it is more difficult to follow that pace since they depend on public policies, where states are much slower in adapting to changes. The review defines the concept of computational thinking as the skills of abstraction, critical thinking, collaboration, and problem-solving, among other skills. This publication describes an overview of the state of the art of computational thinking in the Americas, to contextualize and guide the incorporation of computational thinking in basic education schools (Brackmann et al., 2016).

In the review made by Hsu et al. (2019), he bases the main part of his findings on defining and redefining the concept of computational thinking, but lacks a detailed description of the skills that compose it, such as those mentioned in the previous paragraph, and does not touch on the relevance of such skills being incorporated in the TIMSS test, and that this will generate an increase in the gap between countries that have incorporated such knowledge vs. those who have not yet done so. He mentions Chile as an example, but in that country, the National Digital Languages Plan is more of an idea that is still not implemented in 2022, as there are 2 elective courses for 3rd year and 4th year of secondary education, which schools are not obliged to teach and which in general are not taught because they do not have teachers. Returning to the review of Hsu et al. (2019), it does not mention or inquire how significant it would be to have one or more didactic strategies for teaching computer programming (scaffolding) and thereby transition to computational thinking skills such as abstraction, decomposition, sequencing, algorithmization, and problem-solving-oriented skills.

It should be noted that the present review is a part of a larger research, whose main objective is the construction and validation of a test to be applied in the first year of higher education with computer science students taking the subject of introduction to programming with the Python programming language. Thus, it seems very pertinent to share the results and conclusions of Tang et al. (2020), which conducted a thorough review of the assessment of computational thinking. Part of his results and conclusions indicates that of the studies carried out, all of them are made for students in elementary and secondary education, and no dedication to higher education is observed, which is shared by this author, since of all the articles reviewed in the total search, which were more than 200, of which 101 articles were reviewed exhaustively, the focus is undoubtedly on school education rather than at the level of vocational training. Another aspect that is important to note is that the studies were conducted in informal education, which undoubtedly affects student's performance, since there is not the incentive of formal education that implies that failing a subject would lead the student to repeat a course, so the pressure on the student to do well on the test would be greater, and thus, the results would be better (Tang et al., 2020).

In the code-centered review conducted by Kite et al. (2021), they highlight the importance of computational programming for transitioning to learning computational thinking and point out that they recognize the historical relationship of computational thinking with computer science. In the review, Kite et al. (2021) point out that there are significant gaps in the conceptualization of computational thinking, highlighting the teaching of computational thinking and the professional development of teachers who will be in charge of teaching computational thinking, which gives rise to the idea on which new research can be based, highlighting the search for code-centered skills and the search for skills from interdisciplinary practices. It is highlighted that of the 80 articles reviewed by Kité et al. 49% of the published research focused on code, highlighting specific issues of computational programming, such as algorithms, abstraction, modularization, debugging, parallelization, loops, and conditionals (Kite et al., 2021).

The importance of teaching computational thinking through computational programming has the characteristic of being a concrete matter, which allows going from the concrete to the abstract that are the skills of computational thinking. It is beautiful to see the students who make their first program that is taught in programming and that only displays by console the message "hello World," they feel satisfaction and feel that they have made their first achievement, and perhaps without knowing it, they have acquired their first practice of abstraction. One way to integrate computational thinking in all students, says Kite et al. (2021), is to incorporate its teaching in the basic and high school curriculum in a mandatory way, which helps to mitigate the digital divide between students, as opposed to making it voluntary, which will generate students who will have advantages over those who for some reasons or another prefer other types of subjects, whether art, history, or craft workshops (Kite et al., 2021).

Finally, as well as the code-centered review by Kite et al. (2021), the review by Ogegbo and Ramnarain (2021), which focuses on the teaching of computational thinking in science classrooms, stands out. Regarding the conceptualization of computational thinking, both the articles reviewed by the author and the systematic reviews all conclude that there is no agreement on the skills of computational thinking, a concept that remains under permanent construction and is redefined as it is applied in different contexts, such as in the arts, language, or science. It should be noted that computational thinking has important consequences for the teaching of science subjects at all levels of education, primary, secondary, and tertiary or higher, especially now that it has been incorporated into the TIMSS tests, a situation that will mark future generations. For Ogegbo, an important result yielded by his review is the concrete concepts of computational thinking skills, which would be composed of: (a) "Decomposition" skill that involves dividing a complex task into smaller parts into manageable components; (b) "Pattern recognition" which involves identifying and defining trends within a problem; (c) "Abstraction," a skill that involves identifying particular similarities and differences between comparable problems to work toward a solution, i.e., understanding the problem in its timeless dimension and not linked to a particular subject; (d) "Algorithm design," which involves the development of step-by-step guidelines to solve a problem; and "Automation," which involves the use of technological tools to mechanize

the solutions to the problems posed (Ogegbo and Ramnarain, 2021).

It should be noted that both the code-based approach and the science classroom approach have certain similarities in terms of applicability, since in the area of science, applications through the use of code are of greater applicability, which has a greater tendency to obtain concrete results. Computational thinking skills are very important for the society of the twenty-first century, which will allow the generations in formation to insert themselves in the global world in an advantageous way and that the new reality of the digital world is a factor that facilitates life and that the complexity is neutralized by the new set of skills that computational thinking delivers. Several aspects in which computational thinking may impact are that it will increase the gap between those who have their skills with those who do not have it, in addition to being voluntary in some countries and mandatory in others, some will be at an advantage over others, and there is also the economic gap between the countries of those who have already implemented it and currently only make improvements, and those who are still only a topic of discussion that is very distant.

Economic and employment impact

A diagnosis made in 2017 points out that the emerging society seen from the technologicalization, is dictated by algorithms, artificial intelligence, automated processes, and robots, which impacts the work and the population, a scenario that does not bring good hopes for those who are not part of the doings in technology, because the technological era will bring workers, low wages, and unemployment. This is the uncertainty of millions of people in the world. The advance of automation threatens at least 14% of current jobs in the world, a figure that has been ratified by the OECD for the last 2 years. In total, 14% of jobs in the 36 richest economies in the world have a high probability of being automated (García, 2018).

A study by McKinsey Global Institute indicates that in Chile, 3.2 million jobs could be replaced by automated systems in the next 20 years. In more developed nations such as the USA, the impact of automation would be 46% of current employment. But in Mexico, the McKinsey report estimates that robots and software could do 52% of the work that exists in that country, while in Peru, the percentage reaches 53%, in Brazil 50% and in Argentina 48%. In the Chilean case, the report estimates that retail and commerce in general would save US$9 billion in wages if 51% of the jobs that have the potential to be automated were replaced; manufacturing industries would save US$6 billion and the administrative and public sector would save US$10 billion in wages. Nationally, the savings in wages would be US$41 billion (Manyika et al., 2017).

The speed of substitution of human labor by automated systems is also affected by demographics. On the one hand, it is expected that by 2050, over one-third of the world's population will be over the age of 50, an indicator that only covered 17.5% of the world's population in 1950. On the other hand, according to published analyses, people over 50 years of age have limitations when performing complex tasks involving technology, being largely surpassed by people of younger ages. This is consistent with the studies that point to the conclusion that the older a country's population is, the greater the acceleration in the adoption of automated systems. The latter would explain why, in relative terms, countries such as the United States and the United Kingdom lag behind Germany, Japan, and South Korea in industrial robotics (Rivera-Taiba, 2019).

In this work, among other things, we seek to link the effect of the advance in the implementation of algorithms as executors of repetitive functions at work, which will leave out of the labor activity a significant number of jobs and those who work in them around the world. Thus, jobs such as accountants, secretaries, cashiers, truck and bus drivers, warehouse workers, and instructors in various areas will be the first to lose their respective jobs. Other professions such as doctors, engineers, architects, and researchers are less feasible to automate; however, there will also be certain types of functions of these professionals that will be automated. In this context, it is important to have adequate training in information technology to be competitive in the world ahead, since in the future, there will be two main categories of jobs: either you are highly specialized or you will have to dedicate yourself to the area of services such as gardening or delivery.

Conclusions

At the conclusion of this review, and after having read and analyzed a multitude of articles, of which dozens of them correspond to other reviews, the author, as a computer science engineer, notes that research runs on two separate threads, on the one hand, the various computer implementations developed by computer engineers and, on the other hand, educators, This has generated that in those countries where the teaching of computational thinking has been implemented or is in the implementation stage, there is a lack of trained teachers in computer science to carry out such a monumental task, and where there are, they are absolutely insufficient. The concept of computational thinking and the skills that compose it are still being discussed in education, whereas computer science publishes multiple applications that educators do not understand or do not have the tools to

transfer this knowledge to the new generations through the educational system.

In the analyzed and compared reviews of Shute et al. (2017), Moreno-León et al. (2018), Hsu et al. (2019), Li et al. (2020), Tang et al. (2020), Kite et al. (2021), and Ogegbo and Ramnarain (2021), among others, coincidences were found in that all the articles take as initial reference (Wing, 2006) from where the concept of computational thinking and its skills were mentioned and defined for the first time. Afterward, there are coincidences that there is no consensus among researchers regarding the skills that define computational thinking, and finally, we all agree that computational thinking is the fundamental skill of the twenty-first century. As for the differences between the reviews, they are rather superficial, some spend more time on qualitative research, and others on analyzing quantitative research, but no significant differences are evident.

From the reviews and articles read, the contribution made by Grgurina (2021) stands out in her work entitled "Getting the Picture: Modeling and Simulation in Secondary Computer Science Education," in whose work she incorporates the concept of modeling and simulation as foundational skills of computational thinking, so that it includes formulating problems, organizing and analyzing data logically, representing data through models, and automating solutions. Thus, looking toward school-based training, these skills enhance attitudes such as: confidence in dealing with complexity, persistence in working with difficult problems, tolerance for ambiguity, the ability to deal with open-ended problems, and the ability to work with others to achieve a common goal and communicate it. Grgurina describes computational thinking in terms of its main concepts, such as: data collection, data analysis, data representation, problem decomposition, abstraction, algorithms and procedures, automation, modeling, and simulation.

From the comparisons with the aforementioned reviews, it stands out that the present review emphasizes the lack of evaluation instruments at the three educational levels to measure the computational thinking and the inexistence of didactic strategies to implement the teaching of computational thinking, in this sense, it will propose in two future publications a didactic methodology for the teaching of computational programming and a test to measure its results. It should be borne in mind that something that is not mentioned in any of the reviews is that computational programming is the necessary scaffolding for teaching computational thinking, so it is necessary to differentiate from those who see both concepts as synonymous, when in fact, they are two different rungs of the same ladder. The above implies that it will necessarily be necessary to implement the teaching of computational programming as a previous step for students to acquire the skills of computational thinking.

Undoubtedly, the implementation of computational thinking in the educational system: primary, secondary, and tertiary, which will prepare future professionals with the skills of the twenty-first century, is of utmost importance in terms of its progressive impact on the future of humanity. It should be noted that in countries where computational thinking is being implemented in schools, it has become a fundamental policy, so that these countries are the ones who will dominate the economy, technology and manage advanced knowledge. Moreover, these countries will train the professionals who will occupy the best jobs, those with STEM characteristics, essentially engineers, doctors, and scientists, among others.

In addition, it should be noted that these countries are mainly located in Europe, Asia, Oceania, and North America. Unfortunately, the countries of the continents of Africa and Latin America are not in this group of advanced countries, with the exception of some, such as Brazil, Colombia, Peru, Chile, and Argentina, among others, whose universities are working on projects aimed at implementing computational thinking in schools. This leads to the conclusion that in the coming decades, the socioeconomic differences between rich and poor countries will become even more extreme. Thus, the poorest countries will see their development possibilities diminish and their economies will continue to be based on mineral extraction and tourism.

When comparing the progress of countries in the teaching of computational thinking in schools, it is necessary to see the progress of the states in public policies that establish this subject in the compulsory curriculum, as is the case of England in 2013 and the countries of Europe in general since 2016, or other Asian countries such as Japan, South Korea, and China where computational thinking is defined as the skills of the twenty-first century and will be the engine of technological and economic development. However, in developing countries, such as Latin America and Africa, although there are several initiatives of universities in doing research on the teaching of computational thinking, the states have other priorities, so the issue is not in the discussion of public policy, but rather, the development of the teaching of computational thinking is done by particular initiatives of universities and some other foundation, which leaves them behind in the race to create and develop new technologies to deliver better employment alternatives and thus greater welfare to the population.

However, there is still hope for those countries where large investments in technology are arriving and leading to the hiring of many professionals and technicians in the technological area, which has prompted the updating of the educational system, at least in the interest of meeting the growing demand for advanced professionals, which begins to turn the machinery of the state, which slowly show proposals for the implementation of computational thinking in schools. An example of a European-rich country is England, which implemented the teaching of computational thinking in schools since 2013.

It is also diagnosed that in the coming years, there will be a high number of jobs that will be automated, jobs such as supermarket cashiers, bank tellers, truck and bus drivers,

warehouse operators, and accountants, and all those that perform repetitive tasks and that constitute activities that can be performed by an algorithm. This will inevitably lead to massive job losses of 3 to 4 million in the case of Chile in the next 10–20 years, and in developed countries where, although the impact will be less, it will also cause greater social and economic instability.

A guideline proposed to countries that have not yet begun the process of implementing the teaching of computational thinking in schools should be the following:

- Put the subject in the public discussion.
- Governments should seek the support of experts in technology and education to make a diagnosis of the situation.
- Implement an educational reform that incorporates the teaching of computer programming in compulsory education.
- That teacher-training universities update their curricula to incorporate the teaching of programming languages such as Scratch, Alice, and Python, so that they can successfully implement the new challenges.
- That industry becomes a part of the educational process by investing in software development and educational robotics in order to push the teaching process in an accelerated manner.

Finally, in the language subject, Scratch should be learned to generate animations of the stories they have to read, to make the subject entertaining and responsive to the children's concerns. In natural sciences, some aspects of nanotechnology, its elements, and how infinitely small things are part of our natural world should be shown. In history, different levels should incorporate all the continents, and their history can be recreated with Scratch or Alice applications, building applications such as Age of Empires. In the arts, designs should be created with apps, not working with paintings, which besides being messy, limit creativity, and move away from the central focus, which is technology training. Educational robotics and gamification should be the main branches that collaborate in the training of future professionals.

The limitations of this review and recommendations to be made

A study that allows us to know the number of teachers trained by country, to teach computer programming and thereby transition to the knowledge of computational thinking.

A gender study that shows the participation of women in the world of computational sciences.

A study that makes an inventory of the instruments duly validated to measure computational thinking at the three educational levels.

A study that quantifies and shows the didactic strategies that exist to teach computational programming.

A study of the universities in the world that have incorporated the teaching of computational thinking in teacher training curricula.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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Digital transformation in times of crisis: Challenges, attitudes, opportunities and lessons learned from students' and faculty members' perspectives

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The COVID-19 crises forced and accelerated digital transformation in higher education institutions. Acceptance of the adoption of digital technologies in those institutions as well as their digital and educational readiness and resilience are important key success factors for this transformation. The objective of this study was to explore challenges, attitudes, opportunities and lessons learned of digital transformation in times of crises at the university level from faculty members' and students' perspectives. The study used Unified Theory of Acceptance and Use of Technology (UTAUT) as a theoretical framework. In order to achieve the objective of the study a qualitative method was used. A total of 14 focus group interviews with 62 faculty members and 37 students were conducted in a mid-size university in Palestine. Thematic analysis was used to analyze data gathered from the focus group sessions. Results revealed many challenges toward digital transformation including technical and pedagogical infrastructure, social conditions, ease of use of software, digital pedagogy and online assessment. There are positive attitudes towards the availability of online resources and digitizing theoretical courses. However, students and faculty members still feel that they are not prepared enough for online education and expressed negative attitudes when digitizing practical courses. In order to achieve effective online teaching and learning, good preparation is a must for both students and lecturers which is not followed in actual delivery. Results also revealed several opportunities and benefits of digital transformation, namely, flexibility and the opportunity to develop new technical and educational skills. Researchers recommend carrying out this study in other universities and within different social and cultural contexts and applying mixed approach methodology for validating emerged results.

KEYWORDS

digital transformation, remote teaching, digital pedagogy, online assessment, higher education, UTAUT, post-COVID-19

Introduction

Ubiquitous technology and device access have given rise to digital universal connectivity which is a fundamental element that can help build a sustainable and inclusive education model (Leal Filho et al., 2021). More than ever now, higher education institutions, governments, and private sector organizations are working together to improve digital infrastructure. Smartphone devices, tablets, and chromebooks are becoming powerful and effective tools to bridge the digital divide. Online platforms such as learning destination sites (LDS) and learning management systems (LMS) are transforming learning experiences by allowing the learners to access and download courses, manage and track progress, take notes, and actively participate in discussions with peers and co-learners (Bekova et al., 2021). Virtual communities of practice are empowering faculties to adapt to the evolving pedagogy and course work through resource sharing and curating engaging classroom experiences (Hodges et al., 2020). Digital curriculums are enabling curriculum-aligned, next-generation assessments that can provide automatic grading, support prompt feedback, track reasoning and understanding through strong analytics from different data sources (Ertmer, 1999). Many institutions around the world are embracing these important changes in an era in which the future of education - past the pandemic - will be characterized by blended and hybrid classrooms (Sevnarayan, 2022) with focus on engagement, satisfaction, skill development, and career outcomes - as key education quality metrics (Torres, 2021).

During the past years, the COVID-19 pandemic has posed unprecedented challenges for universities and for the education ecosystem in general. The crisis revealed the vulnerability of the traditional HEI model of teaching that is based on the physical use of the campus for teaching supported by peripheral services (Leal Filho et al., 2021). The crisis also exposed the digital readiness of universities showing that even if digital tools are readily available, the *ad hoc* use of digital technologies does not necessarily enhance teaching and learning (Ng'ambi et al., 2016). Furthermore, the pandemic highlighted and renewed concerns about socio-economic aspects of inequalities in education as students from rural and low-income families have less access to resources at home (Sims et al., 2008; Oyedemi, 2012).

As the COVID-19 pandemic rapidly spread across countries at the beginning of 2020, the Palestinian higher education ecosystem was severely disrupted and affected. The disruption came as a result of the Palestinian National Authority (PNA) implementing different measures to curtail the spread of the virus from social distancing to complete lockdown of campuses. As university campuses shut down, emergency response teams in universities jumped into action by implementing "remote/distance teaching" makeshifts to keep, at the peak of the pandemic, more than 200,000 Palestinian university students learning. In Palestinian universities, faculty members mitigated the disruption of campus closures caused by the pandemic by moving many of their courses, learning resources, and assessments online (World Bank, 2020) – as part of a necessity rather than a strategy to build resilience into teaching and learning.

Therefore, the transition from on-campus teaching to remote teaching was sudden, unexpected and emergency-driven. Many of the faculty members were relatively new to the online environment and were unsure of how to set up their teaching for success. Because the sudden shift happened in the middle of the semester, the adjustment to the new situation had to be quick - but was difficult to plan - as faculty members had different levels of preparedness when it came to designing and delivering course content in online format.

Students have been particularly affected as they suffered varying degrees of learning losses. Outside the campuses, learning losses may manifest in even greater long-term challenges. Without remediation, learning gaps could stay with the students as they transition to the labor market, potentially exasperating inequality. Furthermore, learning gaps are often compounding which means that if they are not tackled promptly and effectively, students are most likely to fall further and further behind (Torres, 2021).

This exploratory qualitative research aims to understand how the COVID-19 pandemic shaped student and teacher experiences with teaching and learning in a mid-size university in Palestine including lectures, seminars, lab-based courses, practical classes as well as their satisfaction with different aspects of the semesters.

According to the education sector strategic plan (Ministry of Education and Higher Education - MoEHE, 2017), one of the main components of improving higher education in Palestine is expanding and encouraging digitization of education and developing e-learning programs and digital content. Higher education institutions in Palestine as well as higher education institutions worldwide started to recognize digital transformation not only as a matter of enhancing quality but as a necessity and a growing need. The pandemic that imposed a sudden shift toward online remote teaching and showed how much the educational systems are in need for such a transformation.

This study took place in a mid-size university in Palestine targeting both faculty members and students in eight faculties: Art, Music and Design, Art, Business & Economics, Education, Engineering & Technology, Law & Public Administration, Pharmacy, Nursing & Health Sciences and Science. A middle-size Palestinian university has 119 academic programs, 445 full-time staff and about 15,000 students. Since 2006 many digitization initiatives have taken place at the university level but they were mostly individual based and mainly used blended learning strategies. One of the most recent efforts in this regard is the digitization of the whole educational diploma program including 24 courses through a Palestinian-Finnish collaboration project titled: Teacher Education without Walls – New models for STEM and Teacher Education in the Digital age (OLIVE, 2022).

In March 2020, Palestinian universities moved to online teaching as the government has announced a national emergency and closed all schools and universities due to the outbreak of the COVID-19 pandemic. This closure severely affected learning and teaching processes not only on the national- but also the

international level (Sun et al., 2022). The crisis showed that educational institutions are not prepared for online learning in terms of pedagogy and infrastructure and that there is a lack of policies that regulate such a digital transformation. Currently the rapid return back face-to-face instruction is also imposing new challenges and higher education institutions are most likely looking forward applying more digital learning and teaching practices within their programs and systems (Abdrasheva et al., 2022).

The purpose of this study was to explore challenges, attitudes, opportunities and lessons learned of digital transformation in times of crises at the university level from faculty members' and students' perspectives.

The research results will contribute to the development of a clear and specific policy that will make digital transformation more relevant to digital practices of both faculty members and students. The results will help also identify challenges and solutions that can support the digital transformation in universities within the Palestinian context. In addition, the results will shed light on possible benefits and opportunities of digital transformation that may contribute to the quality of learning and teaching processes in higher education. Improving readiness for future crises in local and international crises, preparing students to contribute to the digital society.

Therefore, three main questions guided this study:

1. What kind of challenges do faculty members and students perceive throughout digital transformation in times of crisis?
2. What attitudes do they hold toward online/blended learning in higher education?
3. What opportunities do exist while moving forward towards online/ blended learning?

Related studies and theoretical framework

Related studies

The current challenges facing higher education globally have provided universities with great lessons that need to be carefully studied. There have been significant challenges such as closure of universities and an abrupt move toward distance education. In Iraq, as in other countries, the global pandemic has caused sudden shock and disruption to many institutions that were not prepared for it (Leal Filho et al., 2021). The reason for the disruption is that the majority of educational systems are fully implemented based on traditional face-face interaction methods. Additionally, technology is not fully developed and still in the process of finding its place in educational practice. However, the pandemic has made it imperative for our universities to make a quick transition from face-to-face teaching to distance learning so that universities can maintain delivery of education material for their students (Bekova et al., 2021). Students in their first years of college may have suffered more than other, more senior peers due to the dual challenge of moving to the new environment of higher education and also applying distance learning (Hodges et al., 2020). The latter requires special experience and technical tools in which new students might be lacking.

Digital technology has been identified as one of the strategic solutions to be utilized in teaching practices to ensure pedagogical continuity for our students (Ertmer, 1999) and teachers (Coulange et al., 2021). This is especially important since the ongoing health crisis may be long-lasting and we may encounter recurring related events in the future. Universities have made great effort and have taken available feasible actions such as using some free and paid services offered by Google Workspace, Microsoft or other professional bodies. Other universities have moved further professionally with purchasing servers and installing their E-learning platforms and inspecting their computer and network equipment for possible upgrade. Another challenge is that the new software and technology tools require sufficient experience so that when implemented they can handle and manage learning resources as intended. Most importantly, the infrastructure of the whole country in terms of networking and internet services is not fully stable and it can be considered the biggest challenge for all (World Bank, 2020; Torres, 2021).

It is irrefutable that remarkable teamwork has been established from all governmental levels in the ministry of higher education and scientific research and institutions themselves in response to this major health crisis. As an example, many training workshops on educational digital and e-learning platforms were organized and held. Furthermore, universities provided great support to students in all aspects of their education to maintain their learning process. Moreover, lecturers have played a pivotal role in delivering the teaching content online using their facilities and resources such as laptops and internet services. Such considerable cooperation between the ministerial level and institutions, lecturers, and students have led to pedagogical continuity. Despite many success stories, a deep reflection needs to be applied.

In the last 10 years, higher education institutions have been experiencing huge changes in different aspects affected by the advanced technologies and social trends towards digitalization. The revolution of digitalization involved all sectors in societies from production to banking (Marcum, 2014). Nowadays, technology adoption by higher education institutions is connected to the paradigm shift which is forced by technology that enables digital learning (Mahlow and Hediger, 2019). In the context of higher education institutions (hereafter HEIs), digitalization of these institutions is a necessity to attract more and better students through improving the courses materials and training materials (Gurung and Rutledge, 2014).

Therefore, digital transformation (DT) has become a necessity for HEIs in the last 10 years, this transformation becomes necessary and natural for HEIs that seek to be leaders of change and be highly competitive in their field. Datta (2020) defined

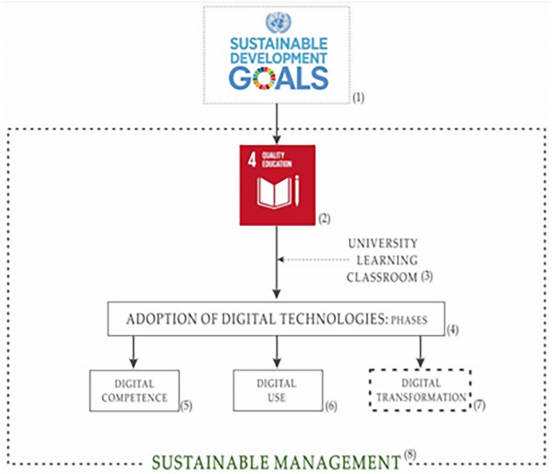

FIGURE 1
Sustainability development model (Abad-Segura et al., 2020).

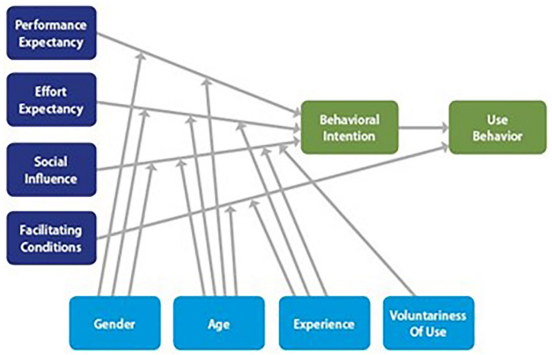

FIGURE 2
Unified theory of acceptance and use of technology (UTAUT; Venkatesh et al., 2003).

digital transformation as a technology-driven process aimed at strategically disrupting and fundamentally improving existing models and operations to achieve continuity and competitive advantage. McTavish and Filipenko (2016) presented digital transformation as a process that integrates digital technology in all fields and requires changes in the areas of technology, culture, and operations. Brooks and McCormack (2020) integrated it within a deep and coordinated culture, workforce, and technology shifts that enable new educational and operating models and transform an institution's operations, strategic directions, and value proposition.

DT is the process that integrate technology in all requires changes and aspects of culture, operations, and policy of higher education institutions (McTavish and Filipenko, 2016). In order to exploit emerging technologies and their expansion in human activities, HEIs should adopt technological initiative and be adapted with the rapid changes in technology through changes in its culture and policy to succeed in the fourth industrial revolution which is DT.

Abad-Segura et al. (2020) developed a conceptual structure on the sustainable management of digital transformation in higher education (Figure 1). From the figure, we noticed that the DT process has different phases including digital competence, digital use, and digital transformation.

Theoretical framework

The framework of this study was Unified Theory of Acceptance and Use of Technology (UTAUT). Venkatesh and colleagues developed the UTAUT model based on previous models and theories such as TAM and TPB. UTAUT model (Figure 2) is composed of four main constructs including: performance expectancy, effort expectancy, social influence and facilitating conditions. Moreover, it has four mediators which are gender, experience, voluntary use, and age. In the context of the study, facilitation conditions refer to the facilitations provided by the institution for the faculty members to teach in online environment during crisis such as professional development and technical support etc. Also, effort expectancy refers to the expected efforts that faculty members need for using online teaching tools compared to the benefits received by that effort. Social influence is related to the peers or other faculty members' influence to use online teaching. Finally, performance expectancy refers to how using the new technology may enhance the performance of users.

Many researchers did not investigate these mediator variables and their influence on the four main constructs (e.g., Ifenthaler and Schweinbenz, 2016; Khlaif, 2018). Various studies in different contexts have been conducted by using UTAUT to investigate the factors influencing emerging technologies such a mobile technology, artificial intelligence, wearable technology and smart technology (Aytekin et al., 2022; Lin et al., 2022; Mishra et al., 2022). The justification of using the first version of UTAUT rather than the extended ones such as UTAUT 2 and 3 was the variance of prediction of the first version was the highest 70% (Gunasinghe and Nanayakkara, 2021) where the other versions between 62 to 66% (Rudhumbu, 2022; Tetteh et al., 2022).

In order to explore faculty members' and students' perspectives toward digital transformation at the university level, it is important to identify their previous experiences, expected benefits and challenges that they have faced during their use of new technologies in learning and teaching processes.

In the context of this study, the research focus group interview questions focused on exploring previous experiences, challenges and opportunities of participants (faculty members and students) in using technology during the pandemic and whether those experiences will help them to attain gains in their university learning and teaching (performance expectancy) and the degree of ease while using those technologies (effort expectancy). The focus group interview method that was used in this study allowed discussions among research participants in order to uncover

others' different opinions and expectations (social influence). In addition, interview questions addressed the degree to which participants believe that the university provided a well-organized and technical infrastructure (facilitating conditions).

Materials and methods

In the current study, the research team employed qualitative approach using focus group interviews to collect data and answer research questions. Focus group is an organized and structured way of data collection with help of a moderator or facilitator of the selected prompts or topics. This research method was recommended to use in social science research for assessing the participants' attitudes, opinions, experiences and feelings (Morgan, 1996) and thus suitable to accomplish the purpose of this study. In addition, the interaction that happens in the focus groups yields significant data and creates spontaneous responses (Butler, 1996).

Participants

The participants in this study were 62 faculty members and 37 students from different faculties in a mid-size university in Palestine. The distribution of the participants is presented in Tables 1, 2.

Recruitment of participants

The deans were approached to invite faculty members and students from the different departments to participate in the focus group. The invitation for participation for both was made open to any student and faculty member who want to participate in the focus group discussions regardless of their preferences and interest in e-learning. Thus, their participation was voluntary.

TABLE 1 Distribution of faculty members on the focus group sessions.

Faculty	Focus group	No. of academic staff
Science	AFG1	12 (6 females, 6 males)
Education	AFG2	3 (1 female, 2 males)
Arts	AFG3	8 (4 females, 4 males)
Law and public administration	AFG4	8 males
Business and economics	AFG5	8 (5 females, 3 males)
Art, music and design	AFG6	5 (2 females, 3 males)
Pharmacy, nursing and health professions	AFG7	9 males
Engineering	AFG8	9 (1 female, 8 males)
Total		62 (19 females, 43 males)

A total of eight focus group discussions were conducted in person with faculty members and six focus group discussions were conducted with students.

Development of the research tool

The researchers developed the focus group discussion questions and the prompts used in the discussion sessions based on the research questions and related studies (Hess et al., 2016; Datta, 2020; Ferri et al., 2020; Bekova et al., 2021). Moreover, the researchers generated prompts based on the discussion in the focus group. Some of the focus group questions were: how do you see university teaching and learning changed after the pandemic? What challenges did you face during remote teaching in the pandemic? What opportunities/ benefits of did the use of technology bring to university teaching? How do you think e-learning/ blended learning may affect the quality of university education? How would you expect/ wish university learning and teaching will look like in 5 years from now? What kind of regulations and policies regarding e−/blended learning would you like to have? Would you be interested to attend short training workshops and/ or capacity-building events that address new technology- based university pedagogies?

Some of the prompts generated in the focus sessions were: e-learning after COVID-19 will be completely different from pre-COVID, what do you think? Can you give an example? "Educators developed their technological skills and knowledge during the Great Online Transfer; what do you think?

Data collection procedures

The researchers sent an invitation to the interested participants explaining the objectives of the study and a link of Doodle to allow the participants to choose the best time for them to attend the focus group session. All of the focus group sessions were held in the main Campus of the university. One of the researchers introduced the purpose of the focus group, discussion protocol of the session, and asked permission to record the discussion. Two researchers facilitated and controlled all focus group sessions by adhering to the preparing focus group discussion protocol. They conducted all sessions in person for approximately 40 to 60 min each. One of the researchers was facilitating the discussion among the participants and the second one was taking notes. After each session, the note taker summarizes the main points in front of the participants and asks them if they agree or not or want to add more.

Data analysis procedure

The researchers followed the procedures reported by Braun and Clarke (2019). The researchers firstly met together to develop the coding book based on the findings of literature and the study

TABLE 2 Distribution of students on the focus group sessions.

Faculty	Focus group	No. of Students
Science	SFG1	8 (6 females, 2 males)
Education	SFG2	6 (2 females, 4 males)
Arts	SFG3	6 (2 females, 4 males)
Pharmacy, nursing and health professions	SFG4	8 (6 females, 2 males)
Engineering	SFG5	6 (3 females, 3 males)
Law and public administration	SFG6	3 (2 females, 1 male)
Total		37 (31 females, 16 males)

framework (Appendix A). Thematic analysis (Ivankova et al., 2006) was used in data analysis by following up the procedures suggested by Braun and Clarke (2019). First, reading line by line by the researchers individually. Second, looking for ideas or concepts based on the study framework. Third, grouping the related ideas or concepts with each other. And finally naming the groups as themes and subthemes based on the similarities of the concepts and ideas. After coding all the transcription files, the researchers meet together to discuss the outcomes of analysis to finalize the themes and subthemes. Any discrepancy and disagreement among the researcher resolved by negotiations, where the inter rater reliability was 89%. The themes were expanded and modified during the analysis. This process was continued until no new theme pattern appeared. Data analysis reached saturation when no crucial insights were added (Lincoln and Guba, 1985). To mitigate subjectivity bias and to provide the triangulation, two researchers reviewed and coded the transcripts independently, then they compared the resulting codes, identified inconsistent cases and reconciled.

Trustworthiness

The process of trustworthiness started from the first point of developing the focus group discussion based on the research questions and related studies, in addition, the questions and prompts were sent to a panel of experts. A pilot focus group was conducted to check the understanding of the prompts and questions. Data analysis was conducted individually and at the end inter-rater reliability was calculated 87%.

Results

Challenges that faculty members and students perceive throughout digital transformation in times of crisis

Facilitation conditions

Results revealed four sub-themes of facilitation conditions as major challenges for digital transformation in times of crises: lack of proper technological devices and software, poor and instable internet connection, cut-off electricity and lack of suitable space for online teaching and learning.

The majority of the participants (students and faculty members) reported that there is a lack of hardware (devices such as computer, camera, scanner, touch screen, interactive pen display, and whiteboard) that are needed to support the teaching process in online sessions. Moreover, many students mentioned that the lack of devices and suitable places deprived them from attending online sessions. All of the students who participated in the current study reported that they do not have fast and stable internet connection for online learning. Although few faculty members reported the cut-off electricity during online sessions influenced their teaching negatively, many students mentioned it as a challenge (Table 3).

Social influence

Results pointed out three challenges in terms of social influence: social context, university life, and social isolation.

All faculty members and students referred that the social environment affected online learning negatively in Palestine. This is because of minimal students' engagement and loss of body language in the online environment. Many faculty members did not turn the camera on during online sessions and/ or during office hours and refused to record their lectures. Also, many students themselves did not open the camera during online sessions. The majority of participants felt that online learning negatively affected students' university life (skills and social contact), since they were not able to interact in person with each other and within the university campus. Social isolation impacted students' life and caused stress, headache, and psychological problems as reported by most of the students (Table 4).

Effort expectancy

Results showed that effort expectancy is another source of challenges that included compatibility of multi platforms/ e-tools and online classroom management.

Most of the participants in the study (students and faculty members) complained about shifting of using various platforms and learning Management Systems during online teaching. For example, some faculty members stress the difficulties of using BigButtonBlue "BBB" due to its unfriendly interface and need for high-speed internet. Other faculty members reported that changing and using new technologies takes more time to learn how it works and how to use it especially when it comes to older faculty member. Most participants suffered the incompatibility between university local platform and other video-conferencing tools like ZOOM and BBB. Some students and faculty members reported that lecturers could not manage and control online sessions (Tables 5, 6).

Attitudes toward online/blended learning in higher education

Results indicated participants' attitudes that can be described as positive, negative and course dependent. As

TABLE 3 Facilitating conditions.

	Academics	Students
Availability of technological devices and software	*"In law faculty, we have 4 cameras only and this is not enough."*(A8, AFG4) *"One of the problems related to infrastructure is the lack of hardware that allows for interactivity – such as touch screens and interactive pen displays – it is obvious that the university did not invest enough."* (A10, AFG1). *"Some teachers and students think that online is only about lecturing on zoom and this is not the case."* (A5, AFG7)	*"One time I had a lab face-to-face, I came to the university and attended the lab, then I had to take an online exam. I went to the library to use the internet, then came to the science faculty – but the internet was slow."* (S7, SFG1) *"... Also, not all students have laptops – and the departments do not have enough hardware devices."*
Internet connection (Wi-Fi)	*"Also from the country's side: electricity and internet outages – and this is an issue."*(A5, AFG7)	"*Internet connectivity is an issue – especially in rural areas - I know of students who put the phone on the window so as to get internet and attend."* (S4, SFG4) *"Even if some companies increased the speed of the internet, still this did not help families who had a large number of children."*(S3, SFG1)
Cut-off electricity	*"Cut-off electricity is one issue that disturb the online teaching, and reduce the students' engagement in the synchronous online sessions"* (A3, AFG6)	*"Some teachers refused to record the sessions despite that the issue of electricity outages."* (S5, SFG3)
Suitable space for online teaching and learning	*"The university does not have large computer labs for exams for students – i.e., 300 students. Labs should be available and cater to the number of students that are in the sections."* (A1, AFG4)	*"We tried hybrid courses – I came to the university to attend a f2f session then I wanted to attend an online session – but did not find a suitable place to attend."* (S4, SFG5)

TABLE 4 Social influence.

	Faculty members	Students
Family support "social context"	*"The social environment does not help here in Palestine. The infrastructure, and there is no family support to help the students when they are young"* (A3, AFG5) *"a Palestinian homes have a large number of family members – songs of this study is inconsistent with the study of nd hence online learning will not work for some homes"* (A4, AFG3)	*"Palestinian homes have large number of family members – and hence it will not work for some homes. "I have other siblings who study online during Covid-19, and this is an issue for my family to offer good internet for all"* (S2, SFG6)
University life	*"The social life in the university is the most important and students sometimes change their careers based on student life in the university"* (A4, AFG5)	*"Student life suffered a lot- especially students among themselves- their relationships are fragmented"* (S1, SFG5) *"It was too flexible for the teachers that they used to give us lectures on Fridays and in the evenings"* (S3, SFG5).
Social isolation	*"With regards to social issues, many students did not want to open the camera or microphone – based on a decision by the university council not to enforce the camera usage – therefore, at the end it is the choice of the student if they want to fully engage in the session or not."* (A1, AFG1)	*"I took 2 courses, the teacher had office hours to zoom in and use the camera and everything. A different teacher was completely the opposite"* (S2, SFG5) "Many teachers refused to record – especially the courses that have politics in it." (S3, SFG6) *"It was too flexible for the teachers that they used to give us lectures on Fridays and in the evenings"* (S3, SFG5).

reported by most of participants, those attitudes were affected by their background, experience with ICT, and teaching experience on online teaching.

Some participants mentioned that online learning can be effective and beneficial for students and teachers, and it is the time to embed it in the higher education system.

However, most participants mentioned that online teaching and learning that happened during the pandemic was a negative experience due to students' poor academic level and un-preparedness for online teaching.

Some participants showed attitudes that are course dependent. They recommended to implement practical courses

(labs, engineering, arts and design and sports) as face-to-face sessions while theoretical courses can be delivered online (Table 7).

Opportunities while moving forward towards online/blended learning

Results showed that participants found also opportunities and benefits while moving towards online/blended learning that are related to performing certain learning activities. Those opportunities were classified under what is called "*Performance Expectancy*" which can be described as the degree to which using e-learning systems will provide benefits to the user. Those opportunities included flexibility and enhancing experience with ICT.

Most of the participants in the study reported that the online system that they use to teach, learn, and communicate with each other was flexible which means that they can use it based on their convenience. Moreover, an individual initiative was established by a faculty member through creating a teaching channel on YouTube as a place to restore all the recorded sessions where students can go back and watch these files. All students stressed the importance of flexibility in online learning to enhance students' achievements as mentioned by some students. For example, also, many students mentioned that the flexibility in online learning during crisis save their efforts through accessing the recorded sessions and their time they save while traveling to the campus. Moreover, few students reported the inappropriate use of flexibility by some lecturers while scheduling the online sessions especially in the weekends and evening time which is considered important for both (students and faculty) to stay with families.

TABLE 5 Effort expectancy.

	Faculty members	Students
Compatibility of platforms/multi e-tool	*"The faculty members – they are mostly older people – and they are not using technology. Some of them quit because they could not use the technology."* (A5, AFG6) "*It is important to integrate Zoom with moodle to record the attendance and reporting students grades"*	*"We had some teachers who had some problems with using technology and tools – especially those who are older"* (S2, SFG4)
Online classroom management	"*We need to use technology tools to control how students take exams."* (A5, AFG7)	"*Some students had a lot of distractions and teachers did not know how to control the session."* (S2, SFG3)

In relation to the opportunity of enhancing experience with ICT, some faculty members mentioned that they learned new e-tools and applied them to their students. Also, most of students reported that they acquired new technological skills and knowledge through using various tools to accomplish the course's tasks.

Other students mentioned that using online learning enables them to enhance their thinking skills more than memorizing information which was an opportunity to practice problem-solving approaches as reported by them. Some female students expressed that online learning helped them to implement the oral presentation and reduced their stress and fear.

Most participants mentioned that online learning encourages students to become independent learners and rely on themselves rather than teachers while some faculty members mentioned that online learning will increase the dependency of students on teachers (Table 8).

Emerging themes from analyzed data

Digital pedagogy and online assessment

Analyzing data revealed a new important construct that needs to be taken into account while using the UTAUT model within the higher education context, namely digital pedagogy and online assessment.

In general, most of students reported that faculty members have a lack of online pedagogical skills such as initiating online discussions, carrying out interactive presentations, and asking questions that affected negatively their engagement and interaction in online environments. Those participants elaborated that the result of un-interactive online lectures *via* zoom led them to be unfocused, feel sleepy and withdraw from courses.

Nevertheless, some students mentioned that some lecturers asked questions and provided feedback during online sessions, this encouraged them to pay more attention to their learning. Another student reported that using Zooms' whiteboard and voting features enhanced the online class interactivity and it was amazing. Some faculty members used a variety of e-tools such as 3-D animation to explain complex structures.

Results showed that online assessment is another major challenge faced by both faculty members and students. All participants reported that online assessment was unfair and unreliable to assess students' learning. This is because some students tend to cheat while others were not provided with enough time to answer online questions. High-achiever students expressed their frustration of this unfair online assessment.

Some faculty members tried to use different strategies to minimize cheating by making test questions more difficult and preventing students from going back to review their answers in previous test sections.

In order to make online assessment fairer, most students suggested using writing essays, conducting online discussions and verbal assessments and solving homework rather than doing

TABLE 6 Attitudes of faculty members and students.

	Faculty members	Students
Positive	*"I myself look at courses – for example – through Coursera, especially through renowned professors– and I myself have benefited from it."* (A1, AFG8) *"There are certain universities like MIT – who have out all of their resources online. I have a certain course that I am comfortable with delivering an online Mechanical Vibrants course."* (A1, AFG8) *"We are in a country that is not stable – so online learning provides the elasticity and flexibility of the system."* (A4, AFG8)	*"I believe that it was a positive experience especially the recorded sessions. I like the online because I concentrate more."* (S2, SFG5)
Negative	*"The Tawjihi grades were high and they do not reflect the academic achievements of the students – and this can be seen that in some of our courses, as high as 55% of students withdrew – so that they will not fail the course."*(A10, AFG1) *"They are weak and do not have a self-learning attitude. The students did not appreciate the online teaching, they did not actively participate."* (A8, SFG4) *"All the online teaching that was done was a reaction rather than a planned action"* (A10, AFG1) *"During COVID, neither the teacher nor the students were ready. We tried our best during that time"*(A1, AFG2) *"The e-learning could be dangerous – as it could sacrifice quality. I know students prefer f2f. Therefore, I believe that core courses should be f2f. The social skills of students are missing"* (A4, AFG5).	*"We had some teachers who had some problems with using technology and tools – especially those who are older"* (S2, SFG4) *"We believe that the evaluation of the students was not fair. Some teachers prefer to give low grades – as it gives more credibility for the teacher"* (S2, SFG5)
Course-dependent	*"In the media, in the practical courses, f2f is preferred – but some theoretical courses can be delivered online."* (A1, AFG3)	*"In the labs, it was a disaster and we suffered a lot during studying online in this pandemic"* (S1, SFG5)

online tests. Few faculty members reported that if online assessment was designed well, it will be effective and prevent cheating (Table 9).

Lessons learned and future expectations

Results revealed that participants appreciate that online learning has the potential to enhance *peer learning and collaboration* between students and faculty members using e-tools and applications. Some faculty members share their experiences and skills with their colleagues to support them.

With regard to *best e-Learning practices*, participants recommended to avoid allocating the large percentage of course grade to online exams and instead to focus on practical skills rather than memorizing knowledge and use alternative assessment methods like project-based evaluation.

Most faculty members agreed with the effectiveness of using future hybrid/ blended learning taking into account nature of courses (theoretical or practical), level of course, pedagogical skills of staff and students' characteristics. Some faculty members suggested that online teaching is more suitable for large discussion sessions and provide better flexibility to the students. They recommend that the university should start with pilot courses from each department, and then this experience can be evaluated and disseminated accordingly.

Some faculty members recommended that face-to-face (f2f) should be the primary learning mode and can be assisted by online learning. They think that students have become reliant on the teacher to prepare everything for them (ready slides, taking notes, content) in online learning, and f2f interaction cannot be replaced for the benefits of interaction and taking notes for students. Students expressed their willingness to have f2f office hours.

In terms of *professional development*, some faculty members referred to the importance of raising their pedagogical and technical skills in online teaching, in particular, in designing online components and deliver blended/ hybrid learning. This can be achieved by providing training and capacity building workshops by establishing a specialized unit at the university.

Few students expressed their dissatisfaction with older faculty members who lack the basics of using technology and tools in spite of having deep knowledge in their fields of specialization. Some students raised the need for training for themselves also as they are not familiar with educational technologies and online resources. They expressed their need for some orientation especially at the beginning of the semester on how to use them in their university learning.

All faculty members recommended setting up a *clear policy* that supports online learning and teaching at the university. The majority of academic agreed on developing a policy for online courses or components taking into account academic load and traveling abroad. Some faculty members emphasized the importance of accreditation; therefore, it should be taken into account while planning a policy for university online learning and teaching.

In blended learning, students recommended designating special days for online learning without mixing them with

TABLE 7 Performance expectancy.

	Faculty members	Students
Flexibility	*"I do not record the online sessions to force students to attend online sessions synchronously"* (A3, AFG3) *"I myself record some of my sessions and I post them on Youtube and I know students go there and watch them."* (A5, AFG1) *"I traveled to turkey and if there are policies available, I can give some sessions online."* (A11, AFG1)	*"We were spending a lot of time at home and we used this time to understand the university regulations. Since we have a lot of time, our GPA increased – because we had more time to study."* (S4, SFG2)."*We also save some time to study – because we were not physically present in the university."* (S2, SFG1)
Enhancing experience with ICT	"*With time, we discovered that we can use a variety of tools for evaluation including exams – and we explored different options in terms of technology*" (A2, AFG5)."*I know there are online tools that we can use even in f2f – for example, online questionnaires – such as google forms and survey monkey*" (A3, AFG5)."*What technology made it easier was sharing of resources on the screen. We discovered many functions in moodle and we use it and students are accepting*" (A8, AFG3)."*Some students did not know how to use it – therefore there should be an entity in the university to make sure that that students are familiar in using such systems and other tools."* (A7, AFG4)	*"In online education, a variety of tools were used – like YouTube and others – we are all able to access these resources. In class, the projector is not as effective as the online screen*" (S1, SFG1)."*Online education has enabled me to depend on my thinking rather than memorizing."* (S1, SFG4) "*Online presentations were easier – because students only used audio and this helped those who had stage fear*" (S2, SFG2)."*What I learned from online education is the importance of the book as the reference. I also learned to find online resources and websites – and this was an advantage. Previously in f2f, the reference of knowledge was the teacher."* (S5, SFG5).

TABLE 8 Digital pedagogy and online assessment.

	Faculty members	Students
Digital pedagogies	"*Some teachers and students think online learning is limited with lectures via zoom, and this is not the case."* (A5, AFG7) "*One teacher used the whiteboard feature in zoom quite a bit – and that was amazing and encouraged me to participate in the activities*" (S6, SFG4)	*For me, I have to see the teacher in front of me in order to understand and to be motivated to participate in the class activities. During online sessions, I cannot concentrate. The outcomes for me were 9 h of failing and 6 h of withdrawal…my experience was bad, I would fall asleep during the lectures – and many teachers did not record the sessions* (A2, SFG3)
Online evaluation	*I myself used to be a coordinator to a java course with 400 students. I created a test bank of 1,500 questions and made sure that students did not cheat. The average was 69 – and in the previous years, it was 71 – which is a true average. Our students are smart and they try to bypass screen locks (safe exam browser). (A3, AFG7)*	*"One teacher did a matching question in 3 min to match 20 items. They give us less time – so as to make sure that we are not cheating"* (S1, SFG4) "*With moodle, another issue is with going through questions. In all of our lives, we learned that hard questions should be left till the end, with ITC, we could not do this – we had to complete the question before we go to the next one*" (S1, SFG2) *'One teacher gave frequent essays to do at home, but at the end all counted for 10% while the exams took the highest percentage of grades*" (S2, SFG6) *"One teacher, We benefited the most from her evaluation method, she gave us virtual exams – 3 questions on the course and this is appropriate for our type of courses."*(S1, SFG6)
Online resources	*"In physical education, there is a deficiency in education resources. I myself prepared in the Gymnastics course 25 online videos– and this helped me during COVID-19. But I did not have resources for other courses…"* (A3, AFG2) *"I looked at many online courses, and unfortunately, there are resources as files that are uploaded on Moodle or Ritaj – and nothing else. I went to an online resource "Phet" and I saw the best simulation there about the collision in physics."*	*"In online education, some teachers showed us chemical structures thru animations. Also, the voting tools were helpful."* (S3, SFG1)

TABLE 9 Lessons learned and future expectations.

	Faculty members	Students
Peer learning & collaboration	*"We need more support from IT person – especially creative individuals – he should be an academic assistant and has strong IT experience. One of our colleagues support us to solve problem while the online session is ongoing"* (A2, AFG4)	"*Some students now use zoom to work together and this was not being done before COVID-19*" (S6, SFG2).
Best e-learning mode	*"I believe that f-2-f is a must and must be the basis – especially for interaction – and the human factor."* (A7, AFG)	*"For large courses that have more than 100 students, f2f or online sessions are the same. Students will not be able to ask questions in either."* (S4, SFG3)
Professional development	*"The faculty members – they are mostly older people – and they are not using technology. Some of them quit because they could not use the technology"* (A1, AFG3) *"Sometimes, to create a small video can take you a whole day – the professor cannot do it all as we all already have full loads."* (A5, AFG8)	*"At the beginning of COVID, some teachers did not have the proper online tools, but later on those became available – but some teachers did not know how to use them – especially the older teachers. I myself used to help this teacher"* (S6, SFG1)
Clear policy for university online teaching & learning	"Ne*xt is the decision maker (the chairperson or dean), they need to take the proper decisions and follow up – but they could not – because of previous negative experiences."* (A8, AFG6) *"If I have a course of 3 credit hours, the expectation of the university is that 6 h are required from the professor. So, 6 h are not enough to evaluate and give feedback"* (A2, AFG2)	"*With the hybrid model, it should be designed well because of possible time conflict – as many students spend much time in transportation."* (S2, SFG4) *"In a hybrid model, it is better to do 1 day online and another day f2f – but not both on the same day."* (S3, SFG4)

face-to-face lectures as this may create conflicts and loses the advantage of staying at home for studying.

All faculty members agreed that design and implementation of online learning or blended/ hybrid learning needs time and effort. However, it is essential for creating good quality online learning.

Few faculty members mentioned the importance of intellectual property of online courses and materials since there were some practices to publish recorded lectures, slides, and videos without teachers' permission. Some faculty members refuse to record their online lectures because of the unique political situation in Palestine and to ensure students' participation in the online lectures. However, some students were annoyed by this practice because sometimes the internet connection is cut and they cannot watch the online session again. A physical education academic recommended preparing a studio for recording/editing videos in the university, and also establish a repository for resources.

Discussion

The purpose of this study was to explore challenges, attitudes, opportunities and future expectations of digital transformation in times of crises in a mid-size university in Palestine.

The major challenges that were outlined in the results of this study included the absence of suitable technical infrastructure for online learning namely lack of digital devices, stable internet connection and learning spaces. Universities in Palestine already had been suffering limited financial resources, they mostly rely on students' fees and have almost no governmental support. As the pandemic crises and need for digital transformation emerged, universities found themselves under huge pressure and the technical gap became more visible and challenging. Previous studies emphasized the necessity of appropriate infrastructure for the success of online/blended learning and digital transformation in higher education (Peimani and Kamalipour, 2021; Silva and Oliveira, 2022). A second major challenge was the social context of the online environment including minimal students' social engagement in the learning process and university life as well as social isolation. Most students were reluctant to open the cameras during online learning due to family and socio-cultural reasons and were not able to come to university campus which restricted social interaction and presence to a large extent and let them feel socially isolated. Related research emphasized the importance of online presence and turning on webcams for both students and teachers during online classes as this will enhance the feeling of community and similarity with face-to-face sessions (Martin et al., 2020; Hosszu et al., 2022). The third major challenge is the effort expectancy in which students and lectures mentioned problems dealing with changing learning platforms and unfriendly video-conferencing interfaces as well as online classroom management. This can be explained by the insufficient digital skills by some students and faculty members. In addition, during the pandemic crisis introducing those new technologies, like Zoom, BBB, Teams … etc., in university

learning and teaching was under urgent conditions and relied on piloting (trial and error) rather than systematic planning (Ismail et al., 2022).

Results regarding attitudes toward online learning, indicated that some faculty members and students expressed positive feelings toward the availability of online educational resources. Students mentioned that some faculty members did not only use ready-made online resources but they also created their own resources and made them online available for all. This confirms that the availability and production of open online educational resources can contribute positively to the adoption of online/ blended university learning and teaching (Almahasees et al., 2021; Pappas and Giannakos, 2021). Negative attitudes from the faculty members' side focused on the inappropriateness of online teaching for students with poor academic level und those who are not well prepared for self- and online learning. From students' perspectives, the procedures that faculty members took to reduce cheating in online courses generated negative attitudes toward those courses. They felt more reluctant to attend if courses are offered online. Other participants mentioned that their attitudes toward online teaching is course dependent, more specifically they expressed positive feelings for adopting it in theoretical courses and negative feelings when it comes to practical courses. The findings of this study are completely congruent with previous studies in terms of the factors influencing attitudes such as the individual characteristics "self-prepared" (Sandanayake, 2019) as well as the course design which was connected to the faculty member's ability to design and develop e-content suitable for online teaching and learning (Saed et al., 2021).

Results related to opportunities offered two main aspects: flexibility of online environment and acquiring new technical and educational skills for both students and faculty members which is consistent with the finding of Singh et al. (2021) who developed a model to find out how the flexibility influence work flow in tele home. Online environment helps to overcome space and time barriers (Saed et al., 2021), also it provides diverse tools of online communication (Alawamleh et al., 2020). Teaching and learning in online environments provided opportunities to enhance skills of using online tools and producing online materials as well as strategies of self-learning and evaluation (Reif-Stice and Smith-Frigerio, 2021).

As results showed that digital pedagogy and online assessment play an indispensable role in the digital transformation at the university level, it uncovered a huge shortcoming in this aspect. Faculty members expressed their unpreparedness for online teaching despite their strong content knowledge in their fields of specialization. This can be explained as faculty members are good and competent researchers in their areas of specialization but did not have the opportunity to develop their pedagogical skills needed for design and implementation of online/ blended learning in higher education context (Thomas and Thorpe, 2019; Almahasees et al., 2021; Bruggeman et al., 2021). Faculty members did not apply online assessment based on sound educational foundations, they simply transferred their traditional face-to-face assessment tools and practices to online environment. This created frustrations and feelings of unfairness of online assessment. In addition, many faculty members while trying to reduce online cheating did not use effective educational measures, on the contrary, new problems emerged. A new study conducted by Cahapay (2021) revealed various challenges of using online assessment during crisis such as unstable of internet connection, electronic power interruptions, and distraction which these findings supported by the findings of our study. Moreover, one of the challenges of using online assessment was time which put students under pressure and finish the task online (Mahdy and Sayed, 2022).

Conclusion

We found in this research that there are many challenges toward digital transformation during times of crises at the university level including technical and pedagogical infrastructure, social conditions, ease of use of software, digital pedagogy and online assessment. We also found that there are positive attitudes when it comes to online resources and digitizing theoretical courses and negative attitudes when students and lectures are not well prepared and digitizing practical courses. In addition, we found several opportunities and benefits of digital transformation, namely, flexibility and the opportunity developing new technical and educational skills. In order to make digital transformation in universities possible, we need the development of all the above in a holistic and integrated manner as well as the guidance of a clear and concrete policy at the institutional level.

One of the limitations of this study that it was implemented in one university in Palestine using only focus group interviews as a research data collection tool. In addition, the methodology was a qualitative approach which has the limitation of self-reported by the participants. Further research including more universities using mixed methods approach to validate the reported results and the new themes that have emerged.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

AA: conceptualization, supervision, project administration, and funding acquisition. AA, GY, GH, and ZK: methodology, investigation, writing—original draft preparation, and writing—review and editing. GH and GY: formal analysis. AA, GY, and ZK: resources. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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Supplementary material

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Knowledge in digital environments: A systematic review of literature

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There are several meanings of the term "knowledge" that match to the diverse study areas. A knowledge creation, sharing, dissemination, and presentation environment is required. Digital platforms and technology lead to the development of innovative methods of teaching and learning in a digital environment. It is of intellectual and academic interest to determine if knowledge processes change in digital contexts, which provide more options than conventional environments such as books and newspapers. The study is built on an exhaustive examination of prior studies on knowledge in digital contexts. The databases ERIC and Scopus served as the search grounds for the keyword-based inquiry. The collected documents were evaluated to determine whether or not they contributed to the investigation's objective. The cornerstone of our inquiry was a careful review of the remaining 14 studies. For quantitative investigations, the experimental design was the most desired approach, but the case study method was the most preferred method for qualitative research. The objectives of the research employ the terms "knowledge" and "digital environments" either directly or implicitly. Studies were designated as "creating" "creating with cooperation" "acquiring" "presenting" and "sharing" In the research, data was coded in accordance with the responsibilities assigned in digital worlds. In the study, 10 distinct theories and models were referenced. These models and hypotheses are categorized based such as creating, acquiring, designing, and using their interaction with data. In the investigations, the existence of traditional knowledge creation and application has been investigated. In addition, the process's distinction owing to the capabilities of digital environments has been investigated.

KEYWORDS

digital environments, knowledge, knowledge theories, review systematic, education

Introduction

There are many different interpretations of the term "knowledge" that correspond to the many foci of research. A network of cognitive elements that are tightly interconnected and serve to reflect the overarching ideas stored in memory constitutes knowledge (Juuti et al., 2012; Buitrago and Chiappe, 2019; Drozdikova-Zaripova and Sabirova, 2020; Sudakova et al., 2022). The idea that knowledge is "justified true belief" is one of the predominant and most disseminated definitions of the term (Oeberst et al., 2016). According to the findings of the study conducted by Oeberst et al. (2016), the majority of the conceptualizations of knowledge taken from a philosophical point of view share two primary elements in common. The first one has to do with looking for the truth, which is the same thing as being consistent with the facts. The second point is that different conceptualizations of knowledge are individualistic in nature.

When seen from a different angle, knowledge might be equated to power. Knowledge, also known as intellectual capital, is the most important ingredient in the production process and the major driver of wealth creation in an economy based on the accumulation of knowledge (Carlaw et al., 2006; Bedford et al., 2015). Although the definition of knowledge is different, an environment is needed for knowledge creation, sharing, dissemination and presentation. It is a matter of intellectual and academic curiosity whether knowledge processes differ in digital environments, which have more opportunities than in traditional environments such as books, and newspapers.

Digital environment

The digital environment has not had one definition. It is defined according to the research context. In Martin and Quan-Haase (2013) study, an e-book is accepted as a digital environment. It is essential for e-books to include interactive features, as stated by Yang et al. (2021), in order to successfully deliver digital learning outcomes. It is not believed to be adequate to transfer merely the written content to electronic media. Instead, it is required to integrate the possibilities of digital tools, such as connecting to another website, adding video or sound, and so on. In more updated research, augmented reality (Salinas and Pulido, 2017), e-learning platforms (Milenkova and Manov, 2019), digital stories Seckin Kapucu and Yurtseven Avci (2020), and electronic concept maps (Kimber and Wyatt-Smith, 2006; Buitrago and Chiappe, 2019) are seen as "digital environments."

The use of traditional teaching methods in conjunction with digital learning environments has resulted in the creation of new chances for learning that is centered on the student and has facilitated the production of knowledge by the learner (Ng and Ong, 2018). Digital platforms and technologies contribute to the creation of new ways for teaching and learning, for evaluation and self-assessment, and for autonomous learning activities (Terzieva et al., 2021).

Common types of learning that take place in digital environments include learning that is assisted by computers, learning that takes place on mobile devices, and learning that utilizes multimedia, including representations such as text, images, video, and animation, to improve student learning (Chang and Linn, 2013; Ng and Ong, 2018). It has a variety of applications in accordance with the many fields of study. When preparing content for academic use, a clinician, medical educator, or basic scientist, for instance, must conduct the essential process of annotating digital pictures with symbols and language. This is a task that is common in the field of medicine (Goede et al., 2004). Enhancements have been made so that students have more opportunities to acquire ideas and information, magnify ideas and information, change ideas and information, and share ideas and information with one another (Freestone and Mason, 2019).

The breadth and depth of learning may also be expanded through the utilization of content-based digital resources such as videos, podcasts, and webpages. In order for these tools to be considered interactive, there must be adequate time allotted for students to think up their own questions (Wachtler et al., 2016; Freestone and Mason, 2019). Not only do these digital platforms assist more traditional methods of instruction, but they also feature activities that are appropriate for kids who have specific educational needs. According to Forsling (2019), the utilization of digital tools in settings pertaining to special needs may be characterized as the provision of compensating assistance from either a compensatory or a categorical point of view.

It is well-established that the potential of digital tools and resources can provide expression to learners' creativity and imagination (Anshari et al., 2017; Freestone and Mason, 2019). At the same time, as a result of the mediation provided by technology, the linguistic and social activities that we engage in on a daily basis are undergoing substantial transformations (Thorne et al., 2009; Wernholm and Vigmo, 2015). Literacy, in point of fact, has its definition extended and scope debated in a framework that takes into account the use of a variety of digital instruments, such as technological literacy. The incorporation of digital technology into educational settings inevitably results in altered circumstances for the use of reading as a learning resource (Salakhova et al., 2021). The implementation of digital technology in educational settings is frequently lauded as beneficial, despite the fact that other individuals have a more pessimistic outlook on the extent to which these tools may really alter instructional methods (Molin and Lantz-Andersson, 2016).

Digital media opportunities also have the potential to make the presentation of knowledge more effective (Buitrago and Chiappe, 2019). Thanks to the interaction that digital media offers, it is possible not only to present knowledge but also to create or re-create it (Wernholm and Vigmo, 2015; Hauck et al.,

2021). The progressive expansion of technical possibilities and the interplay of the z generation (Desai and Lele, 2017; Persada et al., 2019) and alpha generation (Apaydin and Kaya, 2020; Ziatdinov and Cilliers, 2021) with technology make it impossible to view them from a classical standpoint. This generation, classified as digital natives (Prensky, 2001), need a conceptual framework for how they produce and utilize information in the digital environment, which they view as an integral component of their existence (Kim and Yang, 2016; Šorgo et al., 2017; López-Meneses et al., 2020). This investigation has the potential to support and illuminate the proposed conceptual framework. Therefore, this study is based on the examination of studies containing "knowledge in digital environments." The study will contribute to the literature in terms of shedding light on the gaps in the field for future research.

Methodology

A systematic review was carried out with the purpose of demonstrating how various aspects that emerged from a variety of research have contributed to knowledge in digital environments.

Data collection process

Literature review

A first key process of a literature review has to do with establishing an approach that allows it to be effective and orderly addressed, mainly through the formulation of guiding questions:

1. What are the methods of knowledge in digital environments mostly used in studies?
2. What are the aims of the studies?
3. What activities of knowledge in digital environments are used in studies?
4. What theories or approaches are applied in order to explain knowledge in digital environments?
5. What are the perspectives of studies to describe knowledge in digital environments?

Searching database

A search was completed according to the keywords entered in the ERIC and Scopus databases. "Knowledge" and "Digital Environment" keywords were entered in the ERIC database. Added "Peer reviewed only" and "Full text available on ERIC" restrictions. In the Scopus database, the following search key was entered. The process of the study is shown in Figure 1.

TITLE-ABS-KEY (knowledge "digital environment*") AND LIMIT-TO (LANGUAGE, "english") AND EXCLUDE (PUBYEAR, 2022) AND EXCLUDE (LANGUAGE, "portuguese") OR EXCLUDE (LANGUAGE, "spanish") OR EXCLUDE (LANGUAGE, "russian") AND [LIMIT-TO (DOCTYPE, "ar")].

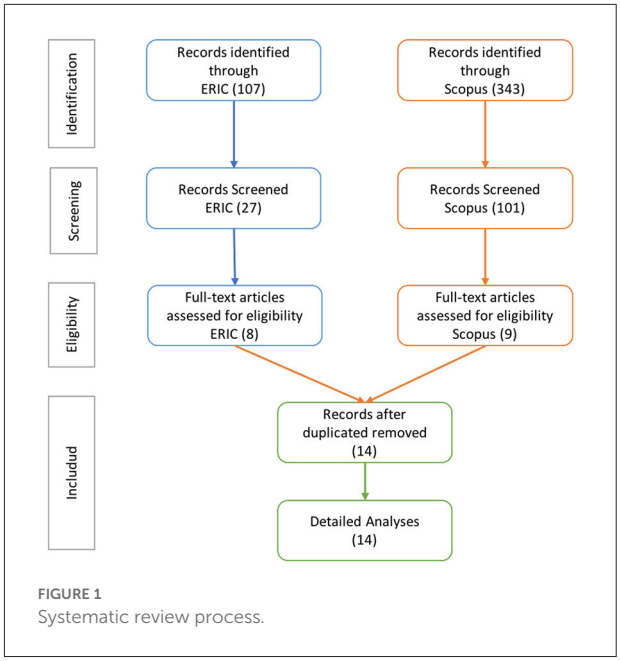

FIGURE 1
Systematic review process.

TABLE 1 Inclusion and exclusion criteria for knowledge in digital environment.

Inclusion criteria
Knowledge in digital environments must be the central topic.
The studies should be published in peer-review journals.
Searching must consider documents published after 2010.
The studies should be indexed in ERIC or the Scopus database.
Exclusion criteria
Notes, editorials, books, and book chapters are excluded.
Knowledge management in digital systems is excluded.
Non-English studies are excluded.

Inclusion/Exclusion criteria

The inclusion and exclusion criteria are presented in Table 1.

Data analysis

Each research team did an extensive reading of some of the studies that were chosen. It was decided what the primary emphasis and goal of each piece would be. The methods and approaches were decided upon at that point. It was possible to determine the theoretical framework and methodological technique utilized in each research. The next step is to investigate the connection that exists between the theory and the topic at

issue. Developed using a knowledge-based coding system. There are four distinct ways in which the processes relating to the idea of "knowledge" are codified. The word "acquiring" is used throughout the research to refer to the process of gathering knowledge and different points of view. When it came to the generation of new knowledge over the course of the studies, he applied the "creating" code. In the study, the "presenting" code was utilized whenever there was an issue regarding the presentation of knowledge. In the study, the "sharing" code was utilized whenever there was an emphasis placed on the exchange of knowledge. The codes were discussed to verify that all of the researchers were on the same page, and consensus was reached over the whole coding process.

Findings

Aims

When looking at the objectives of the articles, it is important to remember that in the digital environment, "knowledge" can be communicated both explicitly and implicitly in the purpose statements. However, in most cases, it is not brought to the forefront in line with the topic of the research. In 9 of the investigations, the term "knowledge" was described as being open, whereas in the other 5 studies, it was described as being concealed (Table 2).

For example, the concept of "knowledge" is clearly included in the aim of the study conducted by Gharib et al. (2020). In addition, "knowledge" was not used directly in the aim of the study conducted by Paek et al. (2016), but the phrase "understanding of new material" was referred to knowledge formation.

When the "digital environment" emphasis is examined, the purpose statements of the study differ according to the subject of the study. For example, in the study conducted by Andresen et al. (2019), the perceptions of people with dyslexia were prioritized in the study, as can be understood from the statement of purpose. "Digital environment" is seen only as an environment. In some studies, the expression of digital environment was implicitly emphasized. For example, from the phrase "interactive blind map" in the aim statement of the study by Balla et al. (2015), it is understood that it is a digital environment.

Methods

When the approaches used in the studies were examined, the qualitative approach was used in seven studies, while the quantitative approach was preferred in seven studies (as shown Figure 2). While experimental design was preferred in four of the studies, the "partial ethnography" design was preferred in one study.

Knowledge

The processes for the concept of "knowledge" are coded in 4 different ways. In the study, the emphasis on obtaining information and perspectives is expressed as "acquiring." He used the "creating" code when it came to the creation of knowledge in the studies. In the study, when presenting knowledge is in question, the "presenting" code was used. In the study, if sharing knowledge was the foreground, the "sharing" code was used.

There are studies that examine the process of creating knowledge in the digital environment. In the study conducted by de Andrés Martínez (2012), students created a blog in a digital environment. In the study, students' blog writing was evaluated as "creating." The students used multimedia materials besides text in accordance with the digital environment. In Seckin Kapucu and Yurtseven Avci (2020) study, the participants were asked to prepare digital stories. During the study process, pre-service teachers created specific knowledge in the digital stories they developed. In this process, they used multimedia tools thanks to digital media opportunities. In another study (Kjällander, 2018), teachers prepared a digital presentation to attract students' attention. Teachers used multimedia tools to create knowledge in these presentations.

In some studies, the process of knowledge creation was handled as a group activity and the process of collaborative knowledge was examined. In the study performed by Hauck et al. (2021), the participants prepared a concept map with group work. While creating an electronic concept map, they created "knowledge" by taking advantage of the possibilities of the digital environment. Since there is an interaction between the participants, the knowledge was created together. In the study conducted by Wernholm and Vigmo (2015), the language used by the users in the Minecraft digital game environment was examined and the process of creating common knowledge was examined.

In Andresen et al. (2019) research, the learning process of participants with and without dyslexia was examined with digital resources. In this process, how much knowledge they acquired was measured by applying the "Word recognition test." In this study, knowledge acquisition in digital resources is at the forefront. The study by Feola (2016) also focused on how knowledge is obtained in the digital environment. Therefore, the study was coded as "acquiring." As shown in Figure 3, the participants interact with digital media tools in the processes coded as "acquiring," "creating," and "creating with cooperation." They play a more active role in this process.

In some of the studies examined, the digital environment was seen and used as a knowledge-presenting environment. In the study of Forsling (2019), digital media was used to meet the demands of individuals in need of special education. In

TABLE 2 The aims of studies.

Article	Aims
Andresen et al. (2019)	This study compared students with and without dyslexia working with multiple information sources on a socio-scientific issue in a digital environment.
Balla et al. (2015)	This study introduces the self-developed interactive blind map teaching-examining e-learning system of the University of Debrecen
de Andrés Martínez (2012)	This report aims to address this concern by discussing design and management of an online learning space for a face-to-face undergraduate Spanish course using proprietary technology.
Feola (2016)	This paper aims to reflect on the implications and challenges that experts in the field have to deal with when you want to evaluate the performance in the use of digital technologies in teaching.
Forsling (2019)	The aim of this article is to contribute knowledge about challenges to literacy development in a digitalized learning environment, with focus on pupils in need of special support.
Gharib et al. (2020)	The purpose of this paper is to extend knowledge about WOM in this new context by proposing a conceptual framework that enables a better understanding of how trust and reciprocity influence eWOM participation in ORCs.
Hauck et al. (2021)	In this paper, we present a digital-collaborative intervention as well as selected results from a first implementation cycle. Here, we will investigate the potential of digital devices to optimize group processes and effective collaboration, a subject where recent meta studies indicate research gaps
Kjällander (2018)	Students' and teachers' assessment interaction with each other, and with digital learning resources—when teachers and students are designing the subject area together, is a focal point in this article.
Koh (2013)	This study explores the ways adolescents create information collaboratively in the digital environment.
Molin and Lantz-Andersson (2016)	This study aims to contribute to the knowledge of educational reading practices by scrutinizing how literacy events evolve in a digital classroom where each student has a personal digital device (1:1), iPads in this study
Noskova et al. (2021)	To identify a diversity of students' information behavior in the digital learning environment, a survey was conducted for the first-year bachelor students of the Herzen State Pedagogical University of Russia
Paek et al. (2016)	The purpose of this study was to examine if student understanding of new material could be promoted by manipulating the perceptual factors experienced at the time of learning.
Seckin Kapucu and Yurtseven Avci (2020)	The purpose of the study is examination of the quality of digital stories developed by pre-service science teachers and deeply investigating pre-service teachers' experiences related to scientific concepts, the characteristics of scientific knowledge and the ways of reaching scientific knowledge in the stages of exploration, storytelling and digitalization.
Wernholm and Vigmo (2015)	The aim of this article is to address how online tools and digital technologies can influence data collection opportunities.

a sense, digital media has been seen as a tool that facilitates the presentation of information. The fact that the multimedia opportunities of digital tools have the opportunity to meet the needs of individuals in need of special education may have been effective in this process. Again, in the study of Koh (2013), there is also the presentation of knowledge along with knowledge creation. Digital media opportunities are also used in sharing the information created in the digital environment. Gharib et al. (2020) examined the eWOM process in the study. Participants can share their thoughts on the product through the digital environment. In the sharing and presenting processes, people are less active in the context of information in the digital environment compared to other processes.

Each study is tagged with multiple codes. Acquiring has five studies. Creating with cooperation is labeled in two studies while "creating" are observed in six research. While there were 10 studies "presenting," "sharing" was found in only one study.

Theories, model and approach

In the papers that were reviewed, a variety of theoretical frameworks were applied in order to explain the results and to design the research. These conceptual frameworks are connected to the body of knowledge that exists inside the digital environment. When this relationship is examined in greater depth, it is possible to categorize the theoretical frameworks associated with it as follows: theoretical frameworks related to the production of knowledge; theoretical frameworks related to the acquisition of knowledge; theoretical frameworks related to the design of knowledge; and theoretical frameworks relating to the use of knowledge (Figure 4).

Three theories have been identified regarding the creation of knowledge; "sociocultural theories of learning," "Social exchange theory," and "zone of proximal development." In Molin and Lantz-Andersson (2016) research, sociocultural perspectives were used, as it is accepted that learning takes place within the

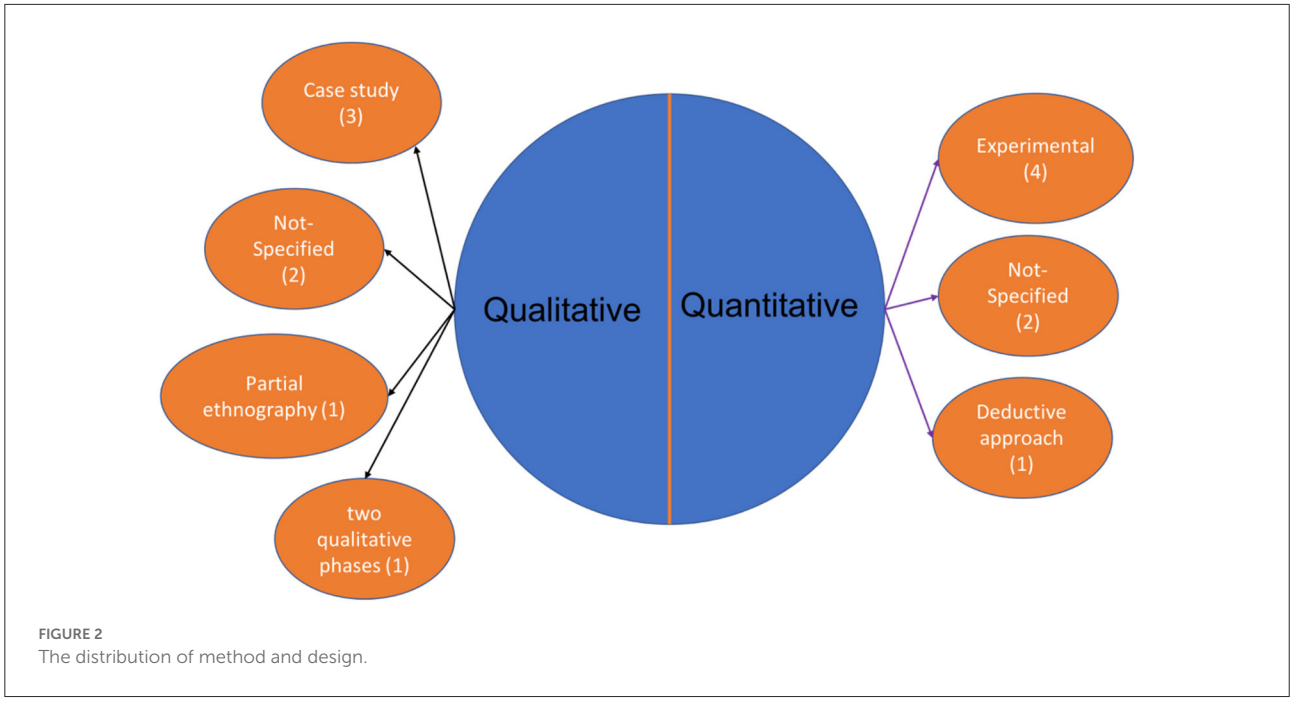

FIGURE 2
The distribution of method and design.

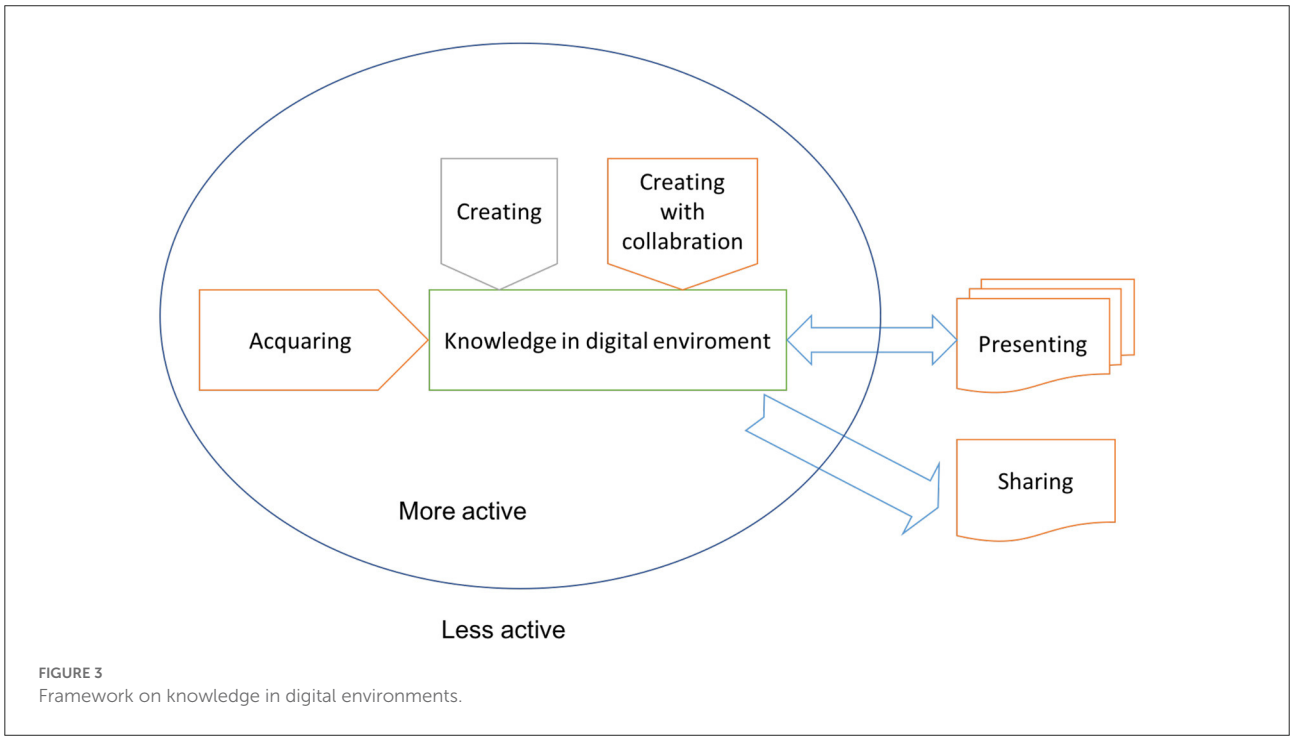

FIGURE 3
Framework on knowledge in digital environments.

activity, context and culture through the interaction between the participants and the tools used in "sociocultural theories of learning." "Social exchange theory" was used in the studies of Gharib et al. (2020). Since the participants share information about the product in the digital environment, this theory was used to make sense of the data. According to the results of the research, the findings are compatible with the assumptions of the social exchange theory, interactions between individuals are reinforced by mutual exchanges. Zone of proximal development theory was used in the study by Wernholm and Vigmo (2015). The language structures used by the participants in the Minecraft online environment were examined. While examining the study

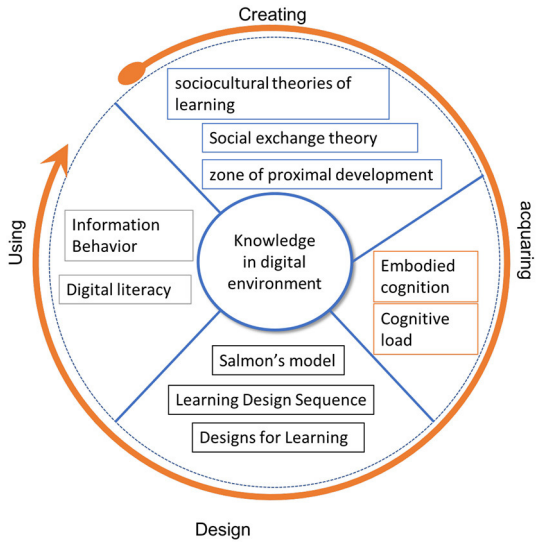

FIGURE 4
Theories used in study to explain knowledge in digital environments.

data, peer influence was examined in the knowledge formed in the participants based on the theory.

In the context of acquiring knowledge, two theories were referred. In the study conducted by Paek et al. (2016), it was tried to determine the perceived factors in the learning process in digital environments. In the study, the "embodied cognition" theory was used because the connections between sensory and motor systems and cognition were the focus. In the study of Hauck et al. (2021), measurements were made regarding the cognitive load of students on the electronic concept map creation process.

Another approach is design theories about how knowledge should be designed for the processes of creation, presentation and sharing. In de Andrés Martínez (2012) study, Salmon's five-stage e-regulation model was followed to facilitate the educational intervention. Kjällander (2018) used the Learning Design Sequence model in the study design. The model is based on a perspective of learning as a multimodal sign-making procedure. Forsling (2019) used the "design for learning" model in his study. Designs for learning is a relatively new and broad field of research based on socio-semiotic and multimodal theories. Design theory is based on communicative possibilities in an increasingly digital environment and how these possibilities affect knowledge and learning conditions.

In two studies, a relationship was established with the "information behavior" institution. In the study of Koh (2013), the information created by the adolescents in the digital environment was explained with the information institution. Noskova et al. (2021) is also associated with the theory of information behavior. The theory is mentioned in the theoretical background. The theory was used while creating the survey. Feola (2016) based her work on the theory of "digital literacy."

Perspective

Andresen et al. (2019) conducted research that analyzed and compared the impact that utilizing digital resources has on the amount of knowledge that students are able to acquire. The cognitive dimension is responsible for its management. The ability to recognize words, working memory, an assessment of topic knowledge, and eye movements were all measured. The participants were anticipating that the digital tool would make it simpler for them to acquire the necessary information.

The research conducted by Balla et al. (2015) relied heavily on the usage of digital maps to depict various pieces of spatial data. It is possible to take use of the benefits that come with being a digital product, but there is no possibility that any new knowledge will be presented using the digital environment.

In the study of de Andrés Martínez (2012), the blog was used to develop the reflective thoughts of the students. Although the students were not examined in the context of the digital environment, the achievements obtained as a result were examined. A cognitive perspective is considered.

The acquisition of the skills necessary to make effective use of digital technology is the primary emphasis of the research carried out by Feola (2016). The method of education through the utilization of the digital tool has, in a sense, been completed. The realization process of learning in the digital environment is not the focus of the study.

Forsling (2019), in his study, investigated how students who require a special education program make use of digital resources to supplement their education. The utilization of digital resources is determined by the requirements of the audience being served. It is believed that the digital environment will speed up the learning process and will make people more productive.

Examined in the research carried out by Gharib et al. (2020) was the manner in which the viewpoint of electronic word-of-mouth, the diffusion of knowledge in the traditional environment, the development in the electronic environment, and the factors impacting this process were investigated. The manner in which knowledge was disseminated, in particular, has been a primary focus of concern.

In the research carried out by Hauck et al. (2021), the production of a product takes place within an electronic setting. During the process of making the product, it was a top priority to create it collaboratively while also including individual contributions. The results from the study were analyzed with both the generation of new knowledge and the sharing of existing knowledge in mind.

In the study of Kjällander (2018), electronic materials were taken in all their dimensions. The processes of obtaining information of the students were examined in detail.

In the research carried out by Koh (2013), the procedure for the generation of new knowledge in a digital setting was investigated. The findings of the study are significant in terms of the level of detail they provide on the information process in the digital environment.

The research carried out by Molin and Lantz-Andersson (2016) was analyzed from the point of view of reading comprehension. It is interested in the processes of re-creating knowledge and making meaning of what has been learned. The conventional method of reading comprehension has been scrutinized with regard to its development in the context of the digital environment.

The utilization of digital resources by students was investigated in the study that Paek et al. (2016) conducted. The question of whether or not individuals make use of the learning process is emphasized more than the process itself.

According to the findings of a research that was carried out by Seckin Kapucu and Yurtseven Avci (2020), conventional channels include digital media as well. A conventional approach was taken to analyzing the results of the study.

Classical theories were utilized in the investigation that Wernholm and Vigmo (2015) carried out in order to analyze the language that players employ in online games; nevertheless, the influence of digital media was not discounted in any way.

Discussion

In the studies examined, "knowledge in digital environments" is included in the content. However, in five studies, the word "knowledge" is not explicitly mentioned in the purpose statements of the study. The expression "Digital environment" is also used with reference to different tools such as "interactive blind map." In this case, it is more preferable to use the name of the digital tool used in the scope of the study directly. For example, in the study of Martin and Quan-Haase (2013), "e-books" represent the digital environment. It is intended to contain digital media options such as connecting to another website and adding video or audio. Again, in the study by Troussas et al. (2021), "social network" represents the digital environment.

The experimental design was the most favored method for quantitative investigations, but the case study method was the most preferred method for qualitative studies. The authors of the study employed a methodology and a design that was suitable for the type of research being conducted. In this way, it is appropriate for both approaches and can accommodate a variety of design configurations because to its adaptability. The fact that he carried out studies by different disciplines may have been effective in this regard. The research conducted by Wernholm and Vigmo (2015) is classified as belonging to the field of education. The research conducted by Balla et al. (2015) is classified as belonging to the field of geography, and the research conducted by Gharib et al. (2020) is classified as belonging to the field of knowledge management.

There has been research done that investigate the process of creating new knowledge in digital environments. There were six studies (de Andrés Martínez, 2012; Koh, 2013; Balla et al., 2015; Kjällander, 2018; Seckin Kapucu and Yurtseven Avci, 2020; Noskova et al., 2021) that looked at the process of how new knowledge is formed. Two investigations contributed to the development of collaborative knowledge. The fact that digital technologies make it possible to create content has accelerated the process of gathering information and increased the number of people who have access to it. According to the findings of Milenkova and Manov (2019) research, young people believe that they are capable of readily generating material and making comments on various forms of digital media, including social media. Kimber and Wyatt-Smith (2006) conducted a research in which they investigated the ways in which students' knowledge was created *via* the use of digital technology. The influence of social networks on the generation of new knowledge was the subject of an investigation carried out by Troussas et al. (2021).

The acquisition of new knowledge was the focus of five of the research in this review. The ability to communicate with more people and acquire more knowledge is made possible by technologies like the internet. A rise in data quantities, quality, and experimental precision has been attributed to the capture of digital information, as stated by Bond et al. (2007) in the field of digital media. When readers acquire new information from the web, they need to identify relevant information from credible sources and integrate this information into a coherent mental representation across a variety of web pages, types of media, and frequently conflicting perspectives before integrating this mental representation with their existing knowledge of knowledge (Andresen et al., 2019).

Eleven research pointed to the importance of presenting and sharing knowledge. There are several benefits associated with the use of multimedia into the information representation process that may be found in digital settings. For instance, video, audio, and even the possibility of augmented reality—all of which are not available in standard print books—offer significant benefits when it comes to the dissemination and presentation of knowledge. The Augmented Reality (AR) technology, with its potential to enable users to see educational information from three-dimensional viewpoints and to help the inspection of three-dimensional objects, among other things (Salinas and Pulido, 2017). In their study, the students were able to learn more about conics thanks to the use of augmented reality (AR) technology into the curriculum for teaching conics. As a direct consequence of this, digital surroundings have a significant impact on the display of information in a variety of different ways.

In the evaluated studies, a range of theoretical frameworks were utilized to explain the results and construct the research. These conceptual frameworks are associated with the digital environment's corpus of knowledge. When this link is investigated in further detail, the corresponding theoretical frameworks can be classified as follows: Theoretical frameworks associated with the creation of knowledge, the acquisition of knowledge, the design of knowledge, and the use of knowledge. The focus of the discussion is not the discussion of the contents of the aforementioned theories and models. The use of these theories in the context of knowledge in digital environments is also determined in other studies.

Three theories have been identified regarding the creation of knowledge; "sociocultural theories of learning," "Social exchange theory," and "zone of proximal development." The majority of researchers who work in the learning sciences, educational psychology, and instructional systems technology are familiar with situative theories, and many of these researchers now embrace situative theories and/or related sociocultural theories as a primary orientation in their research (Hickey and Andrews, 2018). In addition to these researches, a significant number of other studies (Barnard et al., 2019; Peters et al., 2021; Ebenezer et al., 2022) dealing with online education and digital settings have been linked to sociocultural theories of learning. Social exchange theory has been used in studies (Gündüz and Akşit, 2018; Chia-An Tsai and Kang, 2019; Shehab et al., 2019) to figure out how people who share knowledge and people who are looking for knowledge act. The notion of the Zone of Proximal Development is relevant to a generalized issue scenario, which is the successful use of information and communication technology (ICT) in students' and own teaching processes (Quaicoe and Pata, 2018). The concept of Vygotsky's Zone of Proximal Development, which was introduced in Vygotsky (1978), has been utilized to provide an explanation for the findings of numerous researches (Impedovo et al., 2018; Baker et al., 2020; Dentith and Winfrey, 2020) conducted in the context of the digital world. In the context of acquiring knowledge, two theories (embodied cognition and cognitive load) were referred. Both embodied cognition (Gandolfi and Clements, 2018; Musetti and Corsano, 2018; Georgiou et al., 2021) and cognitive load (Zhampeissova et al., 2020; Skulmowski and Xu, 2022; Wang et al., 2022) theory have been used effectively in research on digital media. Another approach is design theories about how knowledge should be designed for the processes of creation, presentation, and sharing. Salmon's five-stage e-regulation model (da Gama Silva et al., 2019; Motaung and Makombe, 2021), Learning Design Sequence model (Hrastinski, 2020; Reyna, 2020), and design for learning model (Dickinson and Gronseth, 2020; Rabinowitz and Tondreau, 2022) are preferred in digital environments. In using knowledge in digital environments dimensions, information behavior (Kurniasih, 2019; Lee et al., 2022; Yavetz and Aharony, 2022) and digital literacy (Baterna et al., 2020; Barnes and Potter, 2021; Çetin, 2021) theorical framework are applied.

Conclusion

The study is predicated on a literature review of previous research on knowledge in digital environments. The ERIC and Scopus databases served as the search grounds for the keyword-based investigation. The retrieved papers were scrutinized to see whether or not they contributed to the goal of the investigation into the topic. A detailed analysis of the remaining 14 papers served as the foundation for this investigation. The experimental design was the most favored method for quantitative investigations, but the case study method was the most preferred method for qualitative studies. The terms "knowledge" and "digital environments" are used explicitly or implicitly in the aims of the studies. Studies were labeled as "creating," "creating with cooperation," "acquiring," "presenting," and "sharing." In the studies, the information was coded according to which roles are given in digital environments. Ten different theories and models were referred to in the studies. These models and theories are classified according to their interaction with information as expressed in Figure 4. In the studies, it has been examined whether there is traditionally the formation and use of knowledge. In addition, the differentiation of the process due to the possibilities of digital environments has also been examined.

According to the results of the study, creating, using, presenting, and sharing knowledge in digital environments should be examined in more detail. It is also suggested for future research how information processes will change according to the possibilities of digital tools. Studies using different theories and models can also be conducted. Unlike research in psychology, which is driven by concepts, research in educational technology is driven by empirical evidence (Means, 2022). The production of new knowledge cannot be immediately observed. On the other hand, research on instructional technology tends to include a greater amount of visible data. Taking all of this into consideration, research may be carried out to compile the findings of educational technology research *via* the lens of educational psychology. This study includes studies indexed in ERIC and Scopus databases and published between 2010 and 2022. In both databases, there may be articles that will contribute to the non-indexed field. The inaccessibility of these studies is a limitation of the study.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

RP and MR: analysis, editing, and writing. AK and NR: writing, analysis, design, and supervision. AP: writing, analysis, and design. AC: analysis and editing. All authors contributed to the article and approved the submitted version.

Conflict of interest

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

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Student's digital competences in Belgium and Romania: A comparative analysis

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This research explores students' digital competences level in three major universities from Belgium and Romania, based on a combination of seven core skills: communication and collaboration skills, creativity skills, critical thinking skills, information skills, problem-solving skills and technological skills. We applied a quantitative design based on an online survey, applied during March 2021–May 2022 using Confirmatory Factor Analysis. The study focuses on examining the qualifications and implementation of students' digital abilities in Romania and Belgium, looking for similarities and differences. The results indicate that students from Belgium have higher average scores for communication and collaboration, information, and problem-solving digital skills than the other skills, while, in the case of students from Romania, creativity and technological skills have the highest average scores compared to the other digital skills. In addition, significant differences between countries regarding the average scores of critical thinking digital skills were not found. Although having a basic understanding of digital competences is advised, improved policies are required to promote the development of these skills as the skill sets needed for information and communication technology employees are more demanding.

KEYWORDS

digital competences, communication and collaboration, creativity, critical thinking, information, problem-solving, technological skills

Introduction

Nearly every aspect of our life is impacted by the digital world, and this trend is only continuing. Technology has produced occupations over the last decades that we could never have envisioned years ago. The modern digital revolution is being driven by the transition from analogue to digital electronic technologies. 99.2% of the storage capacity in the globe in 1986 was analogue, while 94% of the world's information storage capacity had been converted to digital by 2007 (Owens and Padilla, 2021). Based on the phenomenon of

transforming analogue data into binary data (or "digitization"), digitalization represents a major trend shaping society and business at large (Reis et al., 2020; Schallmo and Tidd, 2021). Digitalization improves business relationships between customer and companies, offers new prospects for generating income and value and brings added value to the whole economy and society (Annarelli et al., 2021). To comprehend and manage the changes brought on by the evolution of information and communication technology (ICT) as a person passes through the different periods of life, digital skills are required. A new emphasis is placed on the significance of the comparative studies as an increasing number of young adults enter the employment stage. While everyone has to have a basic understanding of digital competences, ICT professionals have more extensive skill requirements. Without these abilities, there is a chance of exclusion. People must possess the knowledge on how to utilize technology securely and safely to fully activate all the opportunities of digitalization. Digital skills boost young people's self-assurance in using technology for daily tasks, education, employment, or entertainment. Having access to digital devices is necessary but not sufficient for skill development, there are other factors that affect students' ability levels. Also, although there have been benefits to using technology in education, this does not necessarily indicate that teachers can successfully integrate it into their lessons (Farjon et al., 2019).

As of 2014, the Digital Economy and Society Index (DESI) reports have been used by the European Commission to track the digital development of its member countries. Explanatory chapters in DESI provide a European-level assessment across important digital domains, which is crucial for supporting policy decisions. Country profiles in DESI assist the Member States in pinpointing areas which require urgent action. Two nations that are disposed differently in relation to this index are Belgium and Romania. Belgium is positioned in the middle of the scale, while Romania is at the bottom (European Commission. Digital Economy and Society Index (DESI), 2021a). This positioning represents a significant reason in order to compare the digital condition of these two countries. Thus, the discussion and correlation of the six factors that make up the digital skills measured by the Index and the development of both Romania and Belgium in this area are the main objectives of this article. Moreover, the discussions of the indicators that measure digital skills are studied among students to have a better understanding of their employability potential in the modern dynamic market. We will also investigate the situation in Belgium to extract and examine the methods that might serve as models for Romanian policies.

Thus, this paper aims to analyze the students' level and use of the digital skills in Romania and Belgium, with specific emphasis on the elements taken into consideration by DESI. The investigation of similarities and differences between these two countries in a specific targeted public is required in order to have a better and realistic perspective on how digital skills are structured and distributed. The paper situates the analysis into a distinct social framework and with the right methodological design it tries to fill the gap in the literature by adding necessary empirical and comparative studies.

The article is organized as follows: in the next section, the state of the art on digital skills is concisely described, then the subsequent parts depict the methodology and data. The last sections present the results of the analysis, conclusions and directions for further research.

Literature review

Digital skills in pandemic times

The coronavirus pandemic reminds us of the importance of digital skills in helping workers and entire organizations to adapt during a time of physical distancing (Xie et al., 2020). When physical distancing mandates started being implemented, we witness to an increase in digital skills demand in many occupations, especially non-IT sectors (European Commission, 2021a). Many businesses that were lagging in incorporating IT technologies have faced many problems. For instance, in sectors such as leisure and hospitality the impact of the COVID-19 crises was high, particularly on financially fragile firms (Lu et al., 2021). Due to government-imposed lockdowns and social distancing many hospitality businesses were forced to temporary close or limit their operations to only take-outs. Similarly, the mobility restrictions determined a sharp decline in hotel occupancies and revenues (Gursoy and Chi, 2020). In the retail and service sectors, where delivering products and services may prove a challenging option, workers' acquired and owned abilities to operate digital technologies proved to be helpful in avoiding lay-offs and bankruptcies (Xiang et al., 2021). The COVID-19 pandemic has also severely affected the healthcare system by creating a tragic imbalance between needs and resources, which determined a sharp increase in the negative effects of disparities with respect to the social determinants of health. Studies show that patients in minority groups registered a higher mortality rate than the rest of the population and a significantly lower prospect of accessing high quality medical care (Badalov et al., 2022). In terms of digitalization this sector actively moved many activities toward telemedicine and telehealth solutions which allowed a more effectively use of the scars resources and limited the physical contact between medical personnel and patients (Tran et al., 2020).

In many private and public businesses to assure continuity and to build resilience to future crises numerous jobs were fully or partially transformed in digital jobs. This digital economy required different digital skills that may differ from one country to another, according to their level of development and their technological progress. Also, in terms of age, younger generations have a digital advantage relative to other generations, at least in countries where access to technologies is granted (International Labour Organisation, 2020a). Other studies reveal that older workers who were working from home during the COVID-19 pandemic (aged 50 years and above) were "digital pushed" to acquire new computer

skills for work or social interactions (Gallistl et al., 2021; König and Seifert, 2022).

Digital skills: Needs and opportunities

The employment market has been significantly impacted by digitalization, which has altered working circumstances, workplace dynamics, and the necessary knowledge and skills. It shaped employment rates, bringing about both possibilities and threats. Numerous studies predict the creation of hundreds of potential professions, however many of those jobs face extinction due to digitalization. Without sufficient digital competences, it is impossible to engage in the economy and the digital society, especially in light of the digital change that the workplace is through in terms of both the composition and the management. In addition to the changes that digitalization brings into the workplace, the prevalence of digital skills has an impact on how individuals interact, develop themselves and live their daily lives.

In this vein, the *2030 Digital Compass: The European Way for the Digital Decade Communication* was approved by the European Commission on the 9th of March, 2021 (European Commission, 2021b). The *Communication* outlined a clear vision, optimal strategies, and tactics for the European Union's effective digitalization by 2030. In order to achieve the shift to cleaner energy, a sustainable, and tenacious economy, such transformation is essential. In an increasingly connected world, the EU aspires to be digitally independent and promote digital policies that enable individuals and organisations to seize a human-centred, environmentally friendly, and economically productive digital future. This entails addressing the current weaknesses as well as quickening the development of the investment. In particular, by giving young people access to educational and training opportunities, allowing them to interact and make connections, they become aware of cultural differences, and exchange information, thoughts, and emotions, ICT has the potential to improve their human, social, and cultural capital (McLoughlin, 2018; Vodă and Florea, 2019). The government's perspectives on youth work should adapt as young people's needs and interests change. To effectively interact with young people and comprehend the problems they encounter online, young workers must strengthen their digital abilities.

Basic and advanced digital skills will be crucial in the near future to maintain society's collective resilience since only citizens who are capable of using technology and a highly trained digital workforce will be truly in control of their own fate and be confident and assertive about their options. However, technology proficiency cannot be linked only to exposure to digital devices. According to research, not all young people are tech-savvy or interested in learning more. For instance, a recent study by Erdin and Uzun (2022) clearly stated that "being a digital native or digitally competent does not necessarily mean that teachers can integrate technology into their classes easily."

It is useful to define the term "digitally literate" while discussing digital skills. Recent models and frameworks have outlined the knowledge, abilities, and characteristics associated with being digitally literate. One such element is the European Commission's Digital Competence Framework 2.1 (Carretero et al., 2018), which is dimensionally structured and includes five components of digital competence: "information and data literacy, communication and collaboration, digital content creation, safety, and problem-solving." The strategic priorities stated by the highest levels of governance, both nationally and internationally, demonstrate the urgent necessity for developing digital competences in education systems. As one of eight major qualifications for "Lifelong Learning" adopted by the European Parliament and Council in 2006, "digital competence" was described as "the confident, critical and creative use of information and communications technology (ICT) to achieve goals related to work, employability, learning, leisure, inclusion and/or participation in society" (Ferrari, 2012). Throughout this work, we will consider the competences above as well as variables such as critical thinking, creativity, informational and technical skills.

Moreover, it is explicit from the *Communication* that the Union institutions and the Member States must work together to meet the aim of a population with strong digital skills and highly trained digital professions by 2030. Accordingly, at least 20 million jobs-openings for specialists in the field of ICT are to be expected, with a convergence of women and men, and at least 80% of those aged 16 to 74 should have at least basic digital abilities. The objectives seem relevant, having in mind the current situation, as Eurostat highlights that only 54% of EU citizens between the ages of 16 and 74 in 2021 have at least fundamental digital skills (Eurostat, 2022). Even while the proportion of people in the European Union who have digital abilities has increased by 3% over the past 6 years, many still lack the essential knowledge and abilities. For instance, 84% of people with a high educational qualification, 80% of the youth (aged 16 to 24), and 87% of students have at least fundamental digital abilities. In comparison, only 33% of those between the ages of 55 and 74 as well as 28% of those who are retired or inactive have at least rudimentary computer skills (European Commission. Digital Economy and Society Index (DESI), 2021a). In another survey (European Commission, 2016), 60,000 eighth graders from 21 different educational systems throughout the world had their computer and information literacy skills evaluated. It was discovered that, on average, 17% of students do not perform at the lowest level on their scale, and that just 2% of students achieve the maximum level, necessitating the use of critical thinking when looking for information online. According to their findings, it would be naive to assume that young people will naturally pick up the digital abilities they require in performing their activities.

As technology is becoming increasingly mobile, literacy practices and the development of digital skills are becoming more crucial (Vodă et al., 2022). Children and teenagers in Europe still lack acceptable levels of digital competence. This tendency is particularly serious for critical and participatory literacy, when

students are required to actively engage with the material and develop their own responses in addition to reading it (European Commission, 2016).

In order to establish a comparable situation, we shall examine the situation in Belgium, the Member State that is situated in the centre of the current index of the digital economy and society. Belgium is the second-best performer in the EU when it comes to firms educating their employees in ICT for digital skills, coming in at number 12 out of the 27 member states, with a performance rate of 33% compared to the average of 20% across the EU (European Commission. Digital Economy and Society Index (DESI), 2021c). The Belgian government has also increased its efforts to address the need for students to have improved digital skills as well as to reskill and upskill the labour force. In addition, the Dutch-speaking part of Belgium, Flanders, has just recently introduced a brand-new comprehensive digital schooling approach.

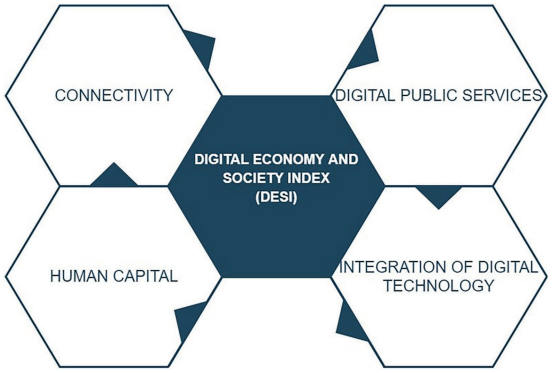

FIGURE 1
Digital Economy and Society Index. Source: authors' representation based on data provided by the European Commission (2020).

Digital progress and performance measurements

The European Commission introduced within the Europe 2020 strategy a performance measurement index to track the digital competitiveness of the European Member states. This analytical tool became one of the main instruments in assessing Europe's digital progress and performance in terms of digital competitiveness. As digitalization disrupts society even more profoundly, countries like Romania must find adequate ways to improve citizens digital skills and cities infrastructures (Vodă and Radu, 2018; Voda and Radu, 2019; Radu and Voda, 2022). According to PwC's Workforce Disruption Index (PwC's Workforce Disruption Index, 2019), in the next 10 years, more than half million jobs in Romania will be affected by the digital transformation generated by new technologies such as automation and artificial intelligence, which will gradually eliminate repetitive activities. The Digital Economy and Society Index (DESI) comprises relevant indicators, grouped in four dimensions/areas (see Figure 1).

- *connectivity* (fixed broadband take-up and coverage, mobile broadband and prices). This dimension is crucial in terms of providing the necessary coverage for online delivery of societal and economic services.
- *human capital - digital skills* (internet user skills and advanced skills). The second dimension underlines the importance of citizens digital skills, which are essential attributes for the effective use of online learning solutions.
- *integration of digital technology by businesses* (business digitalization and e-commerce). In the COVID-19 pandemic situation, governments worldwide had to take actions in order to reduce the spread of the virus. Some measures imposed include: physical distancing, restrictions on the freedom of movement and the closure of non-essential companies (International Labour Organisation, 2020b; Neștian et al., 2021). Given this situation, businesses had to rapidly adapt and make contingency plans to respond to the new measures as they arise. Given the pandemic evolution many companies were forced to embrace technology to move online, complemented by their capacity to explore alternative or temporary working arrangements (e.g., working-from-home; Turnea et al., 2020). However, in European companies the integration of digital technologies had different outcomes that differed according to the size of the enterprises: e.g., Small and Medium Size Enterprises exhibit a lower capacity of integration in comparison with large companies (European Commission, 2020).
- *digital public services* (e-government). Digitizing public services is an imperative action that needs to be considered, as it helps governments meet public expectations and become more efficient and resilient. Digital interactions are also less time consuming for individuals and help significantly reduce transaction costs for the public sector (Daub et al., 2020). Also, unlike the physical office, the delivery of 24/7 public services are likely to produce high benefits for both public administrations and users.

We analyzed the students' level and use of the digital skills in Romania and Belgium, with specific emphasis on the following skills: Communication and Collaboration digital skills, Creativity digital skills, Critical digital skills, Information digital skills, Problem-solving digital skills and Technical digital skills.

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Communication and collaboration

The ability to effectively use ICT to transfer information to others is the emphasis of the communication variable we are referring to in this study. Internet communication skills were defined by Van Dijk and Van Deursen (2014) as the capacity to encode and decode data in order to create, comprehend, and exchange meaning with other individuals utilising message systems like e-mail, chat rooms, or instant messaging. The major elements of this variable, according to Siddiq et al. (2016), are transferring information—using ICT to successfully communicate information and ideas to diverse audiences utilising a range of media and online formats. Moreover, the ability to attract online attention, the ability to experiment online for improving the decision-making process, the ability to pool knowledge and exchange meaning with others in peer-to-peer networking, and the ability to exchange meaning to reach decisions and realise transactions while understanding the meanings of others are all part of this skill. The ability to use ICT to create a social network and operate as a team to share information, reach agreements, and make choices while maintaining respect for one another is related to the collaboration variable. According to Helsper and Eynon (2013), involvement in debates and interactive communication are the two main elements of the ITC's collaborative dimension. Users should generate meaning through exchanges with the help of a variety of modern ICT tools, such as online platforms.

The digital tools provide young people with faster access to information as well as basic assistance, an immersive solution that may be available at all times, and a level of daily services, regardless of a person's location or willingness to reveal their identity. These benefits are seen from the perspective of communication and collaboration. Moreover, despite the fact that young people are exposed to harmful content online, technology-powered solutions can open up new possibilities by detecting, discouraging, and preventing online hate speech by warning users about the possible harm that their activity may create. For example, *Watwat.be* is a youth-focused online information platform in Belgium coordinated by the NGO *De Ambrassade* with assistance from the Flemish Government. The platform's goal is to educate and advise internet consumers to improve their online experience and to better collaborate with other users. In Romania, we can observe that numerous organisations, like the NGO *Digital Citizens Romania*, organise activities for kids, teachers, and parents as part of the EU's mission to enhance the population's digital abilities The events point out the development of basic online communication skills and fundamental coding abilities through the use of free online platforms like *Scratch* or *Code.org* and take place in different settings, from face-to-face activities to online meetings.

Creativity

The creative aspect of digital skills is concerned with using ICT to develop new or previously undiscovered ideas, or to handle traditional views in a novel way and turn them into products, services, or procedures that are considered innovative in a given domain. According to Hinrichsen and Coombs (2013), the creation of content – using ICT to come up with new ideas or find innovative ways to do things – is the most crucial element of the creative digital capability. Due to their frequent use of technological resources, young people are accustomed to the internet and new technologies. Of course, being "digitally native" does not automatically mean "digitally literate" (ICDL Europe, 2014). Having an early exposure to technology and using it naturally and easy (Tapscott, 2008) do not equate to the mastering of the entire range of digital skills (collaborative, creative or critical evaluation skills). Though these new tools give young people new opportunities, they are not simply consumers but also creators. For example, blogging and vlogging have grown to be quite popular for presenting various concerns to a broader audience and for creating a community around relevant topics of discussion.

The digital world offers a vast array of possibilities, from the ability to acquire knowledge and educational resources to the chance to express themselves, help shape their identities and interact with others. Van Dijk and Van Deursen (2014) define content production competence as the ability to produce content of a standard that is suitable for publication online. Moreover, the creative dimension comprises elements such as developing digital content from existing online material and interactive ways of keeping in touch with other users.

To better understand the creative skills Romanians and Belgians pose, we can look at the social media stats reported by Statcounter. The social media market share suggests that 78.05% of Belgian online users prefer Facebook to other social networks (Statcounter, 2022a), while 96.97% of Romanians use this platform (Statcounter, 2022b). Though Facebook is a relatively easy-to-use social network, we can see its great potential for generating creative content. On the other hand, the use of Pinterest – the image-based social media network – is more prevalent in Belgium, with 9.51% of the social media market share, whereas in Romania it only covers 0.75%. While the documented benefits of using Pinterest as a professional resource are typically focused on business, the platform has also been deliberately employed in educational settings to foster the development of creative skills. This is due to Pinterest's visual and organising features (Teach Thought Staff, 2012).

Critical thinking

The ability to think critically on the digital platforms suggests that the users should see the ICT as a tool to make informed decisions about online information using reflective analysis and sufficient proof to substantiate the findings. Sharing opinions and networking are two of the main purposes of digital media, but they can also increase the risk of social isolation offline and prejudice against people with different opinions. *The Digital Education Action Plan* (European Commission, 2018) emphasises

the risks associated with exposure to enormous amounts of data that are mostly driven by algorithms. These risks call for critical thinking and a complete approach to digital social inclusion. Disinformation does not only happen in the online environment, but it has so far been able to effectively take advantage of both the flaws in the digital world and the weaknesses in humankind as a whole. Disinformation operations frequently deftly sidestep or quietly hinder rational thought in favour of preying on people's emotions rather than their reason or critical thinking. Individual users who express their ideas online often go beyond the role of merely information consumers and instead become co-authors of the original message. The most vulnerable demographic in the face of the problem of disinformation is young people, who are the primary users and producers of content through social media.

The essential elements for defining the critical thinking dimension, according to Lee et al. (2016), are clarification – the employment of ICT to ask and respond to inquiries clarifications; assessment – the use of ICT to evaluate a source's applicability to a specific issue; and justification – a user can utilize ITC tools in order to find credible arguments to support assertions with relying heavily on their congruence with other knowledge claims. Moreover, digital users could benefit from developing digital critical thinking skills to connect facts, issues and problems to that they can propose insight for dialogue. The result of the combined and coordinated efforts of all relevant and targeted agents, including national governments, European institutions, academic organizations, media and, last but not least, individual consumers of virtual content, should be in the fight against disinformation in the social media era and could certainly benefit from the improvement of digital and critical thinking abilities.

Information

An individual who is "capable of recognising when information is needed and has the capacity to search, assess, and apply the necessary information successfully" is said to be information literate by Van Dijk and Van Deursen (2014). Users who perform well in the informational dimension find it simple to conduct online searches for information, are adept at using a variety of search-related tactics, find it simple to choose the right keywords to use when conducting online searches, and feel comfortable selecting search results after considering more than the top three results pages. Additionally, users frequently examine material from many websites to determine its veracity and rely on their assessment of a website's credibility. Above all, information literate users carefully analyse the data they obtain online and make sure to use their critical thinking abilities in order to evaluate the search inquiries results. Information skills are the aptitude for finding, choosing, and assessing data from the digital environment.

As we can see from the definition above, this digital skill's essential elements are accessibility, evaluation, and management. Accessibility is the use of ICT to locate and extract information from various online sources, evaluation is the use of ICT to determine whether or not the information is significant for a given purpose, and management is the use of ICT to organise information so that it can be found later. In terms of accessibility, Bulgaria has the lowest rate of internet access among the EU Member States (84%). However, between 2016 and 2021, Bulgaria, along with Cyprus, Romania, Greece, Slovenia, and Lithuania, saw substantial growth in the percentage of households with internet connections. These increases ranged from 15 to 20 percentage points (European Commission. Digital Economy and Society Index (DESI), 2021a). Romania ranks 10th on connectivity, while Belgium is suffering delays in the implementation of 5G networks, mostly because of the delay in allocating 5G pioneer regions and ranks 16th (European Commission. Digital Economy and Society Index (DESI), 2021c).

Romania's coverage increased in 2020, but overall take-up remained unchanged. Reaching the EU average, fast broadband coverage grew to 87%. The fixed very high-capacity network indicator in Romania is 76%, which is significantly higher than the EU average of 59%. This indicates that infrastructure-based competition is fierce in Romania, particularly in urban regions (European Commission. Digital Economy and Society Index (DESI), 2021b). More studies are required in order to assess the evaluation and management dimensions of the information skill. Information is not always of the same quality, making the assessment of information sources crucial. This requires users to possess certain skills that allow them to verify the accuracy of the data and the validity of the sources.

Problem-solving

The ability to use ICT to conceptually process and comprehend a problem situation in connection with the active transfer of skills to solve a problem defines the problem-solving abilities (Laar et al., 2017). For development, economic expansion, employment, and prosperity in both the national and international contexts, a robust digital economy is essential. The labour force and the categories of skill sets in business and society are significantly impacted by the growth of digital technology. With the automation of repetitive tasks and the resulting demand for new and varied sorts of professions, including more skilled digital technology professionals across all economic sectors, the landscape of employment is changing.

The problem-solving abilities are affected as well by the evolution of digital technologies. In almost all jobs where digital technologies complement existing talents, this transformation is driving the need for digital skills. The demand for a high level of digital proficiency is highlighted once again.

Nevertheless, young people should be encouraged to develop this skill in order to better perform in their professional life, as well as in their personal life, as more and more solutions to household problems can be found in the online environment.

Technic

In the digital environment, technical skills refer to the ability to use (mobile) devices and applications to carry out daily duties and to identify specific online environments to navigate them and uphold orientation. The technical variable, according to Van Deursen et al. (2016), involves navigation as well as ICT knowledge and usage. ICT usage refers to users who can run fundamental (mobile) application operations and access resources for daily use, whereas ICT knowledge refers to users who are informed about the features of devices or apps. Last but not least, the navigation dimension emphasises how simple it is for consumers to maintain their sense of direction while surfing online.

The operational internet skills, such as using mobile Internet, were addressed by the researchers in addition to assessing the technical proficiency (the ability to connect to WIFI networks or to download and install apps on a mobile device). To have a better understanding of the operational internet abilities, additional factors relevant to using the online environment and search engines were also measured.

Data and methods

Study design and data analysis

The paper focuses on analyzing the students' level and use of the digital skills in Romania and Belgium, seeking to identify the similarities and differences between the two countries. This investigation will highlight a better and realistic perspective on how digital skills are structured and distributed in accordance to the specificity of each country. There are evaluated perceptions regarding six digital skills: communication and collaboration digital skills, creativity digital skills, critical-thinking digital skills, information digital skills, problem-solving digital skills, and technical digital skills.

We applied a quantitative design based on an online survey administrated in three major universities from Belgium (Catholic University of Louvain, University of Namur) and Romania ("Alexandru Ioan Cuza" University of Iasi) using different educational platforms (e.g., Microsoft Teams, Zoom) during March 2021–May 2022. Although investment in education and training, as well as their modernisation and adjustment represent a mandatory condition for both economic and social process, several member states have diminished their education and training expenditure (European Commission, 2021b). For instance, even if in the past years the public expenditure on education in both countries was fairly steady, variations between them were considerable (around 6% of GDP in Belgium and around 3% of GDP in Romania). Moreover, in Belgium, there was set up a knowledge and support center for digital school education. In addition, in both countries, in higher education, significant investments were planned for the development of digital infrastructure and digital teaching resources, the adaptation of study courses and digital training for academic staff (European Commission, 2021b).

The questionnaire included three sets of questions: the first one focused on evaluating the students' perceptions regarding their digital skills, the second one referred to questions used for finding the students' perceptions on several directions of action that need to be taken into consideration in obtaining a development strategy in education, and the third one captured both the students' social and demographic particularities and the sources for their digital skills accumulation. In the present paper, we used only the first and the third sets of questions in order to create our constructs measuring the digital skills and to characterize the sample, as presented in Table 1.

A short description of the study goals and the participants' right to quit the survey at any time were included on the first page of the questionnaire. Also, it was mentioned that the anonymity of the respondents will be assured and that there will not be any repercussions in the case of withdrawing from the survey.

Statistical methods

In order to analyze if there are significant differences between Belgium and Romania regarding the sources of digital skills accumulation (i.e., digital education courses and levels of education) and the distributions of the six digital skills, we performed the following test: Pearson Chi-Square, Continuity Correction and Independent T Test. The first two tests are included in the Chi-Square Tests category and refer to testing of the significance of associations between two categorical variables, in our case, variable Country associated, by turn, with the digital education courses enrolment and education. The Independent T test was used in the case of comparing the mean of each digital skill score from Belgium with the corresponding mean from Romania in order to understand whether the scores of digital skills differ based on country (Field, 2005).

In addition, for checking if digital education courses enrolment and education have significant influences on the digital skills, depending on the number of the independent variables' categories, we applied Independent T Test (in the case of digital education courses) and One-way ANOVA (in the case of education). Unlike Independent T Test which is used for comparing two means, One-way ANOVA is a parametric test that compares three or more independent groups in order to identify whether there is statistical evidence that the associated population means are significantly different (Kent State University Libraries, 2021).

Finally, the correlations among the six digital skills at the level of each country were identified by using Principal Components Analysis (PCA). It is a multivariate statistical process which is applied as a data reduction technique in order to identify variables that account for a large proportion of variance in a large data set (Dugger et al., 2022). Particularly,

TABLE 1 Description of the variables.

Variables	Description	Items	Sources
Communication and collaboration digital skills	• The students' ability to transmit information using digital environments and to share online content and media made by them or others and to collaborate with peers. • Number of items: 6	1. "I can communicate with others using Skype, WhatsApp, Messenger, etc. or using basic features (e.g., voice messaging, SMS, text exchange)." 2. "I can use advanced features of several communication tools (e.g., using Skype and sharing files)." 3. "I actively use a wide range of communication tools (e-mail, SMS, instant messaging, blogs, and social networks) for online communication." 4. "I can use collaboration tools (e.g., project management software, online spreadsheets) and help edit documents / files created and shared by others (One Drive, Google Drive, Dropbox, etc.)." 5. "I know I can use online services (e.g., e-banking, e-governments, e-hospitals, online payment etc.)." 6. "I pass on or share knowledge with others online (e.g., *via* social networking tools or in online communities)."	Al Khateeb (2017)
Creativity digital skills	• The students' ability to create content by converting information into new knowledge. • Number of items: 6	1. "I know how to create/edit something new from existing online images, music or video." 2. "I can create digital content (e.g., text, tables, images, audio, video files) in at least one format using digital tools." *3. *"I am confident about writing/ create content on a blog, website or forum."* *4. *"I would feel confident putting writing/video/image content I have created online".* *5 *"I can use tools for creating webpages or blogs".* *6. *"I can create complex, multimedia content in different formats, using a variety of digital tools and environments".*	Van Deursen and van Dijk, 2014 Al Khateeb (2017)
Critical thinking digital skills	• The students' ability to think reflectively and judge skillfully the incoming online information and provide them with a safe, permanent and an easily accessible tool as well as a physical environment and, also, to formulate their own point of view. • Number of items: 5	1. "I know when I should and should not share information online and which kind of information." 2. "I am aware that my credentials (username/password) can be stolen. I know I should not reveal private information online." *3. *"I know how to extract/highlight fundamental concepts and references in the text".* *4. *"I know how to identify and extract specific information in sources like social media".* *5. *"I know that on internet not all information is reliable and I know how to check different sources and evaluated online content".*	Van Deursen and van Dijk, 2014 and Al Khateeb (2017)
Information digital skills	• The students' ability to search, evaluate and organize digital information. • Number of items: 6	1. "I can use advanced search strategies to find reliable information on the internet (such as using web feeds (like RSS))." 2. "I use some filters when searching to compare and assess the reliability of the information I find". 3. "I can assess the validity and credibility of information using a range of criteria". 4. "I can save or store files or content and retrieve them once saved or stored". 5. "I classify the information in a methodical way using folders. I make backups of information or files I have stored". 6. "I can save information found on the internet indifferent formats. I can use cloud information storage services".	Al Khateeb (2017)
Problem-solving digital skills	• The students' ability to find solutions for the problems or to formulate strategies to determine the best solutions for them. • Number of items: 5	1. "I can take basic steps to protect my devices (e.g., using anti-viruses and passwords)." 2. "I have installed security programmes on the device(s) that I use to access the Internet (e.g., antivirus, firewall)." 3. "I know how to react if my computer is infected by a virus. I can configure or modify the firewall and security settings of my digital devices". 4. "I find support when a technical problem occurs or when using a new program". 5. "I can solve most of the more frequent problems that arise when using digital technologies".	Al Khateeb (2017)

(Continued)

TABLE 1 (Continued)

Variables	Description	Items	Sources
Technical digital skills	• The students' ability to continuously adapt to new technologies. • Number of items: 9	1. "I can bookmark a website and I can download/upload files." 2. "I can complete online forms." 3. "I can apply basic formatting (e.g., insert footnotes, charts, tables) to the content I or others have produced." 4. "I know how to reference and reuse content covered by copyright." *5. *"I know how to import data into a specific programs and tools* (e.g., *STATA, SPSS, Eviews, MonkeyLearn, Aylien, Google Cloud NLP API, Amazon Comprehend, Brandwatch, RapidMiner, MeaningCloud)."* *6. *"I know how to do simple data processing in specific programs and tools* (e.g., *STATA, SPSS, Eviews, MonkeyLearn, Aylien, Google Cloud NLPAPI, Amazon Comprehend, Brandwatch, RapidMiner, MeaningCloud)".* *7. *"I can choose the right tool, device, application, software or service to solve (non-technical) problems".* *8. *"I am aware of new technological developments. I understand how new tools work".* *9. *"I regularly update my technical digital skills. I am aware of my limits and try to fill my gaps".*	Van Deursen and van Dijk, 2014 Al Khateeb (2017)

Each variable was defined based on several items (i.e., the higher score the higher skill) with answers evaluated on a five-point Likert scale (1 = strongly disagree; 5 = strongly agree). * indicates that the items were developed by the authors.

PCA transforms the coordinate system of the original data into composites so that the largest variance is along the first coordinate (i.e., Component 1), and the second largest variation in the data is along the second coordinate (i.e., Component 2), and thus these coordinates are called the principal components (Hochreiter, 2013).

Digital skills measures

As mentioned previously, the first section of the questionnaire focused on evaluating the students' perceptions regarding their digital skills. It consisted of 38 items which were created based on the Laar et al. (2017) and van Laar et al. (2020) meta-analysis on digital skills. The reference study focused on seven core skills supported by the use of ICT: communication digital skills, collaboration digital skills, creativity digital skills, critical-thinking skills, information digital skills, problem-solving digital skills, and technical digital skills. Each of these digital skills was evaluated through several items (see Table 1) using a five-point Likert scale in which 1 represents "strongly disagree" and 5 "strongly agree." Most of the questions included in the study for measuring each of the digital skills defined by Laar et al. (2017) and van Laar et al. (2020), were adapted starting from the methodologies applied by Al Khateeb (2017) and Van Deursen and van Dijk (2014).

The constructs for each of the six digital skills were determined by averaging the responses for the items referring to them. However, before creating the constructs, we focused on the analyzing in detail the items and we checked the reliability of the multi-item scales, the convergent and divergent validity.

The reliability of the multi-item scales was verified through Cronbach's Alpha Test and McDonald's Omega Test. Although, the usual range of variation for the results of these two test is [0–1], for exploratory studies, the acceptable values must be situated between 0.60 and 0.70 (Hair et al., 2014). The results presented in Table 2 reveal that, in the two samples (Belgium and Romania), each of the six constructs reflecting digital skills register values of the tests higher than 0.65, offering, in this way, a good reliability of the scales.

Furthermore, for measuring the convergent and discriminant validity, Average Variance Extracted (AVE) and its square-root were calculated at the level of each construct. The convergence of the constructs is assured if the AVE values are higher than 0.50, while the discriminant validity is validated if the values for square-roots of AVE are higher than the ones on the corresponding column and row of the correlation matrix. Taking into consideration these criteria, we can observe from results included in Table 2 that both convergent and discriminant validity are achieved.

Sample and data

The Romanian participants in the study were asked to complete the questionnaire in their mother language. For the respondents from Belgium, the questionnaire was available in English. In this way, we assured that the questions were thoroughly understood by the participants so that eventual errors will not appear. A pilot study involving 20 respondents from each country, excluded from the final study database, was carried out to eliminate any potential issues or concerns. The results from the

TABLE 2 Results of reliability and validity tests.

Variable	Cronbach's alpha	McDonald's omega	Average variance extracted	Correlations between variables					
				1	2	3	4	5	6
Belgium									
1. Communication and Collaboration digital skills	0.736	0.742	0.597	[0.772][a]					
2. Creativity digital skills	0.790	0.794	0.558	0.516***	[0.746]				
3. Critical digital skills	0.690	0.719	0.549	0.557***	0.362***	[0.740]			
4. Information digital skills	0.705	0.703	0.593	0.570***	0.366***	0.516***	[0.770]		
5. Problem solving digital skills	0.682	0.678	0.519	0.496***	0.562***	0.485***	0.514***	[0.720]	
6. Technical digital skills	0.772	0.687	0.541	0.617***	0.643***	0.609***	0.533***	0.645***	[0.735]
Romania									
1. Communication and Collaboration digital skills	0.827	0.832	0.520	[0.721]					
2. Creativity digital skills	0.830	0.826	0.561	0.646***	[0.748]				
3. Critical digital skills	0.821	0.837	0.548	0.592***	0.463***	[0.740]			
4. Information digital skills	0.718	0.717	0.539	0.545***	0.502***	0.649***	[0.734]		
5. Problem solving digital skills	0.809	0.754	0.655	0.468***	0.498***	0.600***	0.496 ***	[0.809]	
6. Technical digital skills	0.786	0.739	0.513	0.608***	0.580***	0.643***	0.604***	0.669***	[0.716]

*** denotes the statistical significance at 0.05 level; [a]The data in the diagonal square brackets are the square root of the A Variance Explained value for each variable.

pilot study were used to ensure that the questionnaire was fit to be used after slight modifications.

A random sample of 300 students is selected from each university, by using the organization database. In order to assure the comparability and validity of the responses in the sample were included only students that had compatible specializations, which determined significant reduction of the selection base. In Belgium, out of the 300 students selected, 127 were willing to participate in the survey, which gave us a total of 89 valid responses In Romania, from the total students that were selected, only 116 accepted to respond to the questionnaire, and 109 successfully completed the survey. Thus, the percentage of the valid responses were 70.08% for Belgium and 93.96% for Romania. The total sample consisted of 207 respondents (89 coming from Belgium universities and 109 from the Romanian university).

Results

Descriptive statistics

This section includes the descriptive statistics for the variables considered in the study. Also, it reveals the results of the comparison between Belgium and Romania regarding the six digital skills and the sources of their accumulation. The digital competences studied in the case of students from both countries were correlated to the age of the students and their educational level as we have focused our statistic on youth from the university background.

Table 3 presents the frequency distributions of the variables Age, Gender, Digital courses enrolment and Education in the case of each country.

In Belgium most of the students were aged between 21 and 24 years old (42.7%) or 25 and higher (38.2%), while the vast majority of Romanian students were aged between 18 and 20 years old (50.5%) or 21 and 24 years old (42.5%). In the total sample, female respondents were preponderant in both countries (68.5% in Belgium and 91.7% in Romania). As we mention, our research is focused on analyzing young university students' digital skills, meaning that age is an important determinant factor. Developed as such, the study will allow us to advance a clear picture of the employability potential of young people from the two countries studied, as the ability of an individual to fulfill their career potential depends on attributes and skills that are developed during their lifetime.

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TABLE 3 Characteristics of students' samples from Belgium and Romania (n=89 for Belgium and n=109 for Romania).

Variable	Category	Frequency	Percentage (%)
Belgium			
1. Age	18–20	17	19.1
	21–24	38	42.7
	25+	34	38.2
2. Gender	Female	61	68.5
	Male	28	31.5
3. Digital courses enrolment	No	60	67.4
	Yes	29	32.6
4. Education	Level 1 (Primary)	4	4.5
	Level 2 (Secondary)	7	7.9
	Level 3 (Tertiary)	36	40.4
	Level 4 (Primary & Secondary)	6	6.7
	Level 5 (Secondary & Tertiary)	14	15.7
	Level 6 (Primary, Secondary & Tertiary)	22	24.7
Romania			
1. Age	18–20	55	50.5
	21–24	46	42.2
	25+	8	7.3
2. Gender	Female	100	91.7
	Male	9	8.3
	No	98	89.9
3. Digital courses enrolment	Yes	11	10.1
4. Education	Level 1 (Primary)	5	5.6
	Level 2 (Secondary)	38	34.9
	Level 3 (Tertiary)	10	9.2
	Level 4 (Primary & Secondary)	15	13.8
	Level 5 (Secondary & Tertiary)	25	22.9
	Level 6 (Primary, Secondary & Tertiary)	16	14.7

Source: authors' calculations based on the Stata statistical analysis software.

The accumulation of digital skills is based on the theory learned and practice completed in the years of schooling and in other courses which are not a part of the scholar curriculum. In both countries, the levels of enrolment in digital courses are low (Table 3), 32.6% for the students from Belgium and only 10.1% from Romania declaring that they followed these type of training in order to enhance their knowledge and practice of the digital skills. This high difference between the two countries can be validated also through the results of the Chi-Square tests applied (Table 4), the p-values corresponding to the calculated values of the test being lower than a significance level of 0.01. According to the results presented in Table 3, the students from Belgium mentioned that, in the years of schooling, the role of the education in achieving the digital skills was mostly preponderant in the third level (i.e., university; 40.4%), while in the Romanian students' case, the second level (i.e., high school) was most relevant (34.9%). Among the students, 24.7% Belgians and 14.7% Romanians said that the digital skills were accumulated in all of their levels of education. The results of Pearson Chi-Square and Continuity Correction for the variable education (Table 4) show that there are significant differences between countries concerning the levels of education in which the students learned the digital skills (p-values lower than a risk of 0.01).

Digital skills in Belgium and Romania

The graphic representation from Figure 2 indicates the mean scores obtained for each of the six digital skills in the case of each country (blue representation for Belgium and green representation for Romania). The digital skills for which were identified the higher scores were Communication and Collaboration and Critical thinking ones, with levels above 4.2 points, but with no significant differences between the two countries. The first type of skills was found to be more predominant in the case of students from Belgium (4.48 points), while the second type was more prevalent in the case of students from Romania (4.39 points) In Belgium, the other digital skills registered average scores between 3.75 and 3.45 points, with Creativity and Technical ones being at the bottom of the list (3.47 and 3.45 points). In Romania,

TABLE 4 Results of testing the differences between Belgium and Romania regarding digital courses enrolment and education.

Chi-square tests	Digital courses enrolment		Education	
	Value of the statistic	*p*-Value	Value of the statistic	*p*-Value
Pearson Chi-square	42.483	0.000	15.376	0.000
Continuity Correction	45.251	0.000	14.012	0.000

Source: authors' calculations based on the Stata statistical analysis software.

Creativity and Technical skills registered not only the same average score (3.48 point), but also the lowest levels In general, the average scores for Information and Problem-solving skills were near 4 points, thus indicating that students from both countries have a high levels of competencies regarding the gathering and using information and solving difficult tasks. Comparing the results for the two countries, Communication and Collaboration digital skills and Information digital skills registered higher mean values in Belgium (4.48 points and 4.05 points) than in Romania (4.29 points and 3.75 points). Contrary, in the case of Critical thinking digital skills, Romanian students had, in average, higher scores (4.39 points) than the ones from Belgium (4.22 points). Finally, Creativity digital skills, Problem-solving digital skills and Technical digital skills do not defer significantly, in average, from

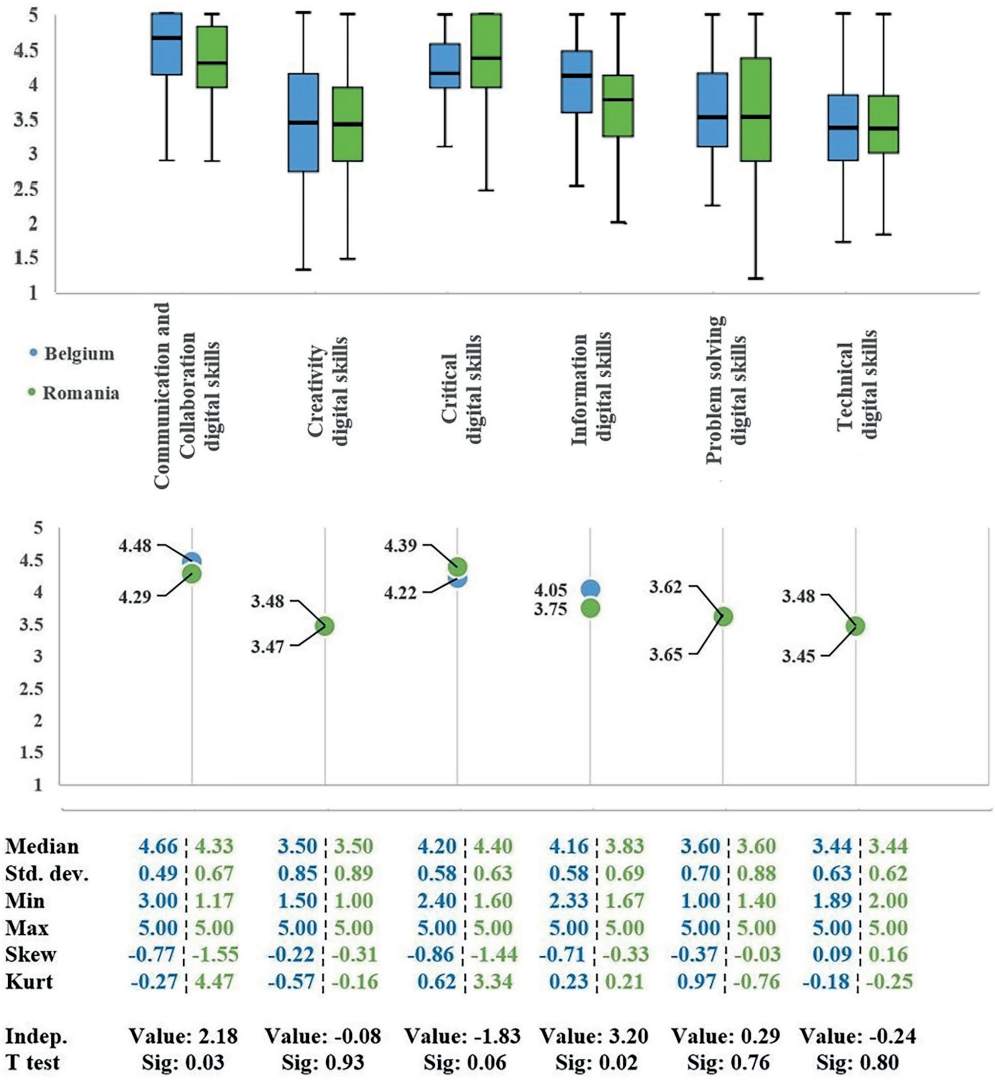

FIGURE 2
Descriptive statistics of the Digital Skills scores for Belgium and Romania. Source: authors' calculations based on the Stata statistical analysis software.

a country to another. Moreover, the Independent T Tests results reveal that, for the last three digital skills mentioned, there is not a statistically significant difference between the means obtained for each of the two countries, *p*-values associated with the T values being higher than a level of significance of 0.10 (value of $p = 0.93$ for Creativity digital skills; value of $p = 0.76$ for Problem-solving digital skills; and value of $p = 0.80$ for Technical digital skills). However, for Communication and Collaboration digital skills, Critical thinking digital skills, and Information digital skills, the results of Independent T Tests indicated statistically significant differences between Belgium and Romania, the *p*-values being close to a risk of 0.05 (value of $p = 0.03$; value of $p = 0.06$; and value of $p = 0.02$).

Other results included in Figure 2 emphasize, in general, negative values for the coefficients of Skewness, meaning that, mostly, the values of the digital skills tend to be in the upper half of the variation range (i.e., 3 and higher). Also, taking into consideration the mean values and their corresponding standard deviations, we calculated the coefficients of variation for each of the digital skills and all of them were lower than 0.50 (i.e., 10.93; 24.42; 13.74; 14.32; 19.33; 18.10 for Belgium; and 15.61; 25.64; 1,435; 18.40; 24.10; 17.97 for Romania), meaning that the distributions are homogenous and the means are representative.

The results presented in Table 5 indicate if the sources of digital skills accumulation (i.e., digital courses enrolment and education) have a statistically significant impact on the scores of the digital skills in Belgium and Romania.

Giving that the variable digital courses enrolment is a binary one, we applied the Independent T Test in order to test if there are significant differences between scores of each digital skill depending on the participation or nonparticipation in trainings. In Belgium, except Communication and Collaboration digital skills and Critical thinking digital skills, all the other types of digital skills are significantly influenced by the enrolment in digital courses: Creativity and Problem-solving digital skill for a 5% level of significance ($t = 2.119$, value of $p = 0.037$ and $t = 2.844$, value of $p = 0.006$); while Information and Technical digital skills for a 0.10 level of significance ($t = 1.795$, value of $p = 0.076$; and $t = 1.894$, value of $p = 0.062$). In the case of Romania, only Information digital skills are significantly influenced by the enrolment in digital courses ($t = 2.190$, value of $p = 0.044$). Taking into consideration the other source of digital skills accumulation, education, the results of the ANOVA test show that in both countries the influence is not statistically significant, the *p*-values corresponding to the F statistics being higher than an acceptable level of significance.

Figure 3 consists of two graphic representations resulted from de PCA analysis presenting the relationships between the six digital skills of the students, the left one for Belgium and the right one for Romania. The solutions identified in the PCA analysis are validated through the results of Bartlett Test of Sphericity and Kaiser-Meyer-Olkin (KMO) Test which verify if the variables are independent (Bartlett, 1954; Kaiser, 1974): the associate probability of the Chi-square test used within the Bartlett Test of Sphericity was lower than the significance level of 0.01 and the value of KMO Test was above 0.6.

In the graphic specific to Belgium, there can be identified two groups of variables around the Ox axis: the above group formed by Critical thinking digital skills, Information digital skills and Communication and Collaboration digital skills; and the below group composed by Technical digital skills, Problem-solving digital skills and Creativity digital skills. In Romania the grouping of the variables around the Ox axis is

TABLE 5 Results of Independent *T* Test and ANOVA test for each type of digital skills.

Variable	Digital courses enrolment Independent *T* Test		Education ANOVA	
	***T* statistic**	***p*-Value**	***F* statistic**	***p*-Value**
Belgium				
Communication and Collaboration digital skills	0.046	0.963	0.733	0.601
Creativity digital skills	2.119**	0.037	0.427	0.829
Critical digital skills	0.059	0.953	1.176	0.328
Information digital skills	1.795*	0.076	0.439	0.820
Problem solving digital skills	2.844***	0.006	1.695	0.145
Technical digital skills	1.894*	0.062	0.531	0.752
Romania				
Communication and Collaboration digital skills	1.117	0.281	0.739	0.596
Creativity digital skills	1.382	0.190	0.821	0.538
Critical digital skills	1.529	0.145	1.439	0.216
Information digital skills	2.190**	0.044	1.453	0.212
Problem solving digital skills	−1.183	0.257	0.746	0.591
Technical digital skills	0.665	0.516	1.108	0.361

***, **, * denote the statistical significance at 0.01, 0.05 and 0.10 level.

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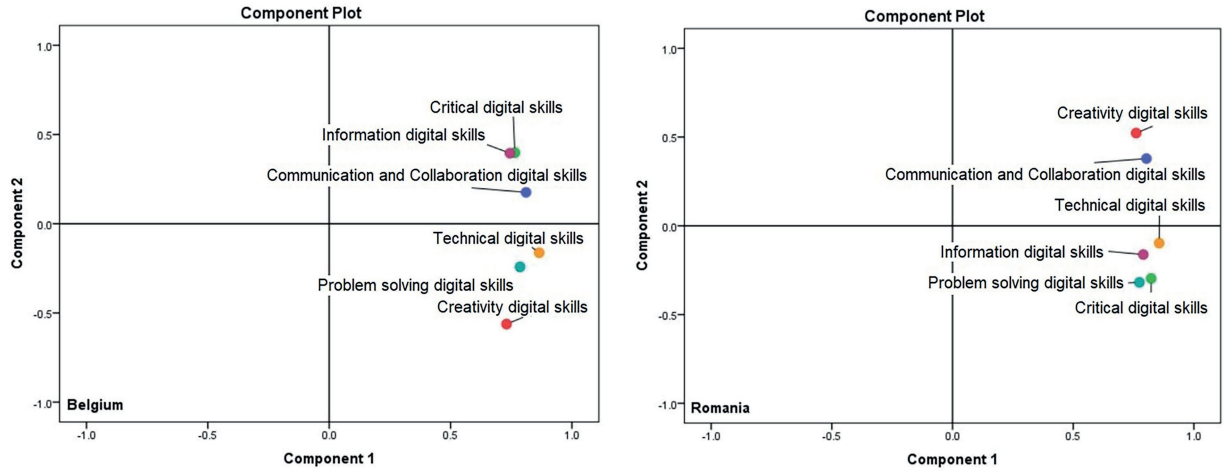

FIGURE 3
Relationships among Digital Skills in Belgium and Romania. Source: authors' calculations based on the Stata statistical analysis software.

different. In the group above the axis are included Creativity digital skills and Communication and Collaboration digital skills; while the other group comprises Technical digital skills, Information digital skills, Problem-solving digital skills and Critical thinking digital skills. The elements from each group are positively correlated (Creativity digital skills with Communication and Collaboration digital skills in the first group; Technical digital skills, Information digital skills, Problem-solving digital skills and Critical thinking digital skills among themselves in the second group), students registering similar scores for them. However, even if correlations were positive at individual level, at group level the results show a negative sign.

Discussion

With more young individuals entering the workforce, there is a renewed focus on the need for comparative studies. Thus, this paper contrasts the digital proficiency of Romanian and Belgian students. These include general abilities like web surfing, email, or instant messaging conversation, as well as the capacity to use online platforms linked to one's field of work and familiarity with digital financial services. Future employment in the online economy will require significantly more sophisticated digital abilities for tens of millions of jobs. By including pertinent empirical and comparative data, the current study also aims to address a gap in the literature.

To determine the similarities and differences between the two countries, the study focuses on examining the students' level and use of digital abilities in Romania and Belgium. The findings indicate that the digital skills of students do not differ considerably from one nation to another. Comparing the results for the two nations, it can be seen that Belgium (4.48 points and 4.05 points) outperformed Romania in terms of mean values for both communication and collaboration digital skills and information digital skills (4.29 points and 3.75 points).

Countries similar to Romania in their digital skills status must develop appropriate solutions to enhance residents' digital competences and city infrastructure as the effects of digitalization on society become increasingly more significant. The communication and collaboration skills that Romanian youth need to develop include the capacity to attract online attention, the capacity to experiment online to enhance decision-making, and the capacity to exchange meaning to deal with different situations and complete transactions while comprehending the meanings of others. The collaboration variable is connected to the capacity to use ICT to build social networks and function as a group to share knowledge, reach decisions, and do so while still showing respect for each other.

On the brighter side, there were no significant differences in average critical thinking digital skills scores between the nations studied. In the first section of the paper, we have stressed the value of acquiring adequate digital competences. It is difficult to participate in the economy and the digital society without a minimum knowledge of digital skills, especially in light of the workplace's ongoing digitalization in terms of management and organizational structure.

Conclusion

Multiple aspects of the human life are always changing due to geopolitical, demographic, and economic factors. Particularly technology is altering the nature of sectors such as education, administration, health, making whole industries and job sectors redundant while also generating entirely new businesses. Governments, company executives, academic institutions, and individuals will need to overcome incentives to focus on the short term and start making plans for a future in which change is the only constant in order to address this supply and demand imbalance.

Young people who are digitally literate can access crucial information and services, conduct online transactions, and explore technology that will enhance their social relationships with friends and family. Additionally, it will present them with more chances to advance in their career or pursue their schooling. The idea behind 21st-century digital skills is that they are necessary for employees to take ownership of their own development and to participate in the knowledge-based workforce. What employees can do with information to boost 21st-century abilities and fully utilise ICT is what matters most (Laar et al., 2017). It is crucial to assist children and teens, especially those who are at risk of exclusion, in developing new skills by offering dependable and approachable assistance as they navigate the complexities of the digital world.

The ability to possess information, skills and attitudes appropriate for a given setting is referred to as digital competence. Consequently, in order to improve digital competence, it is essential to acquire knowledge of technology, practical skills for using digital tools, and a mind-set that encourages critical thinking, operational and informational knowledge, innovation, and creativity. Naturally, a development in the educational system in countries such as Romania and Belgium will result in lower unemployment and a lower danger of poverty, as well as higher living standards and longer life spans (Leiciu and Zafiu, 2021). In this regard, it should be highlighted that raising the digital educational bar in the EU Member States is essential for keeping up with the shifting demands of the corporate world (Tarabasz et al., 2018) and all significant aspects of a contemporary participative citizen (Van Dijk and Van Deursen, 2014).

This research has several limitations that are listed hereby. This study works with data collected at national and international level but includes a limited number of faculties and students from Romania and Belgium, which can cause potential sampling bias. Second, we focused on six digital skills as antecedents of digital competences. Other types of digital skills can be collected to make the analysis more specific. In addition, several factors determining the levels of digital skills among students could provide a more detailed perspective on the specificity of each country and system of education. Third, the study does not take into consideration the modalities through which students are developing the digital skills in each country, a more specific approach being useful to complete the big picture. Finally, the analysis capture student's perception at a given time, and a follow-up study could be conducted to analyze how digital constructs relate to each other from an evolutionary perspective.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval were not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

Author contributions

AV, CG, CC, and GP: conceptualization, validation, investigation, writing—original draft preparation and writing—review and editing. AV, CG, and GP: literature review. AV and CC: methodology, formal analysis and resources. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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Videoconferencing fatigue and online student engagement among Filipino senior high school students: A mixed methods study

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Introduction: The ubiquity of online classes during the COVID-19 pandemic induced the widespread use of videoconferencing applications. However, the prolonged use of these applications can lead to videoconferencing fatigue. Drawing from an online survey sample of 215 senior high school students from a selected private university in Manila, Philippines, this mixed methods study examines videoconferencing fatigue and its relationship with online student engagement (OSE) during the COVID-19 pandemic.

Materials and methods: This study utilized a convergent triangulation research design. The quantitative strand was cross-sectional in nature. The constructs were measured using the Zoom Exhaustion and Fatigue Scale and Online Student Engagement Scale. Bivariate and multivariate statistical tests were used to determine the significance of the relationships between variables. The qualitative strand utilized a descriptive design. Narrative data were collected through an open-ended survey question and analyzed using content analysis.

Results: Quantitative results indicate moderate to high levels of videoconferencing fatigue among student respondents. Moreover, higher levels of OSE were observed among those who endured higher visual fatigue and attended videoconferences more days a week. Qualitative findings demonstrate various manifestations of videoconferencing fatigue among students and relate it with decreased energy to perform academic tasks and learning absorption. However, the qualitative analysis also reveals students' perceived need for videoconferencing to learn online.

Discussion: The nuanced insights from both strands highlight that despite their perceived negative impacts of videoconferencing, students had to tolerate visual videoconferencing fatigue in order to engage meaningfully in online classes.

KEYWORDS

COVID-19, high school, online learning, student engagement, videoconferencing fatigue, zoom fatigue

Introduction

Education is one of the sectors greatly affected by the (COVID-19) pandemic since distance learning has become a need rather than an option. The United Nations Educational Scientific and Cultural Organization (United Nations Educational Scientific and Cultural Organization [UNESCO], 2022) estimated that 91.3% of students worldwide have shifted to online learning since early 2020. The Philippines is one of the several countries worldwide with the longest period of distance learning since March 2020 (Westerman, 2022). The government had initially planned to gradually return classes to on-campus mode in 2022; however, the supposed pilot implementation of in-person classes had been suspended due to the sudden spike of COVID-19 cases in January (Cabalza, 2022). This delay in the resumption of face-to-face and extension of online learning means that students and educators will continue to rely on digital technologies to sustain their engagement in formal education.

Videoconferencing is a particular information and communications technology (ICT) that has become a ubiquitous tool for pure online education at all levels in the country. Videoconferencing can be broadly defined as synchronous or simultaneous visual and audio communication between two or more persons using an electronic device such as a smartphone, computer, and other computing gadgets (Bauce et al., 2018). Even before the pandemic, systematic reviews have established the utility and effectiveness of videoconferencing for educational purposes (Chipps et al., 2012). Videoconferencing applications, such as Zoom, Google Meets, and Microsoft Teams, provide a platform for teachers and students to have real-time, synchronous interactions. These applications offer ICT affordances to facilitate interactive discussions and other class activities. In addition, Videoconferencing helps create and maintain students' social connections with teachers, students, and distant loved ones, especially since in-person interactions had been constrained because of the social distancing and lockdown measures implemented during the time of COVID-19. However, using videoconferencing to participate in pandemic-induced remote education has not been without challenges. Empirical evidence reveals that Filipino students from disadvantaged sectors experience a lack of gadgets and access to reliable Internet to have effective videoconferencing-facilitated classes (Cho et al., 2021). Another problem related to this mode of learning that emerged during the pandemic is the exhaustion and tiredness that students develop because of the prolonged use of videoconferencing applications. This phenomenon is coined as 'videoconferencing fatigue' (Nadler, 2020; Riedl, 2021).

Empirical reports have demonstrated how Filipino students' negative experiences related to using digital educational tools can lead to poor educational outcomes and dissatisfaction with learning (Cho et al., 2021). Furthermore, meta-analytic evidence suggests that academic-related stress is negatively linked to academic performance (Ahmady et al., 2021). Hence, we suspect that videoconferencing fatigue can also be a deterrent to the overall educational experience of students. Specifically, our outcome variable of interest in this present study is online student engagement, which refers to students' skills, emotions, participation, and performance regarding their involvement in online classes (Dixson, 2015).

Literature review

Conceptualizing videoconferencing fatigue

Videoconferencing fatigue is often called *Zoom Fatigue*, as Zoom has become the most ubiquitous platform for this function. The term "Zoom Fatigue" started receiving prominence among journalistic circles to signify the collective sense of exhaustion induced by engaging in videoconferences that had become more widespread during the COVID-19 pandemic (Wiederhold, 2020). This article uses the term videoconferencing fatigue to signify that we are interested in all types of videoconferencing platforms used by students for learning. Videoconferencing fatigue appeared in scholarly literature towards the latter part of 2020, and researchers have since attempted to describe this phenomenon. Nadler (2020) theorizes videoconferencing fatigue as a form of computer-mediated communication exhaustion caused by cognitive over-exertion to interact using these new platforms meaningfully. This substantial increase in cognitive effort can lead to stress during and after videoconferencing. Aside from cognitive load, Bailenson (2021) adds that extended periods of close-up eye gaze and staring at one's face at the screen contribute to videoconferencing fatigue, which is further enabled by the lack of physical mobility during meetings. Epstein (2020) suggests that the lack of synchrony in communication and the lack of sensory dynamism also contributes to the sense of fatigue developed during videoconferencing.

The construct "videoconferencing fatigue" was further developed by Fauville et al. (2021a), who pursued the creation of a psychometrically sound tool to measure the said phenomenon, called the "Zoom Exhaustion & Fatigue Scale" (ZEF). Fauville et al. (2021a) posit that videoconferencing fatigue has five dimensions. The first is *general fatigue*, which refers to the sense of being tired, exhausted, and mentally drained after videoconferencing. Second is *visual fatigue*, manifested by unpleasant eye and vision symptoms induced by videoconferencing. Third is *social fatigue*, which refers to the avoidance of social interactions after videoconferencing. Fourth is *motivational fatigue,* which is depicted by the lack of drive to engage in other activities after videoconferencing. Last is

emotional fatigue, which refers to moodiness and irritability related to videoconferencing.

The development of ZEF (Fauville et al., 2021a) stimulated empirical investigations to explore the prevalence and determinants of videoconferencing fatigue. Majority of the respondents in recent research using this tool demonstrate moderate to high levels of videoconferencing fatigue (Fauville et al., 2021a; Oducado et al., 2021). Evidence reveals that videoconferencing fatigue is influenced by gender (Fauville et al., 2021b; Oducado et al., 2021), non-verbal mechanisms, including face dissatisfaction (Fauville et al., 2021b; Ratan et al., 2021), psychological attributes of users (Ebardo et al., 2021; Fauville et al., 2021a), and nature, duration, and frequency of meetings (Bennett et al., 2021; Nesher Shoshan and Wehrt, 2021; Oducado et al., 2021).

Videoconferencing fatigue in online class settings

Many of the earlier investigations on videoconferencing fatigue prior to the release of ZEF by Fauville et al. (2021a) were conducted in educational settings during the pandemic. A cross-sectional study conducted among engineering students in 2020 suggests that 70% of the students experience zoom fatigue (Asgari et al., 2021). Samara and Monzon (2021) explained that the disruption of the human communication component of learning and the demands to multitask while using Zoom increased the mental and physical aches students feel because of prolonged videoconferencing. Moreover, a qualitative case study has noted that in the context of e-learning, individual, situational, communication, and environmental factors influence the extent university students develop videoconferencing fatigue (Massner, 2021).

On the other hand, there is still a limited amount of literature that utilized ZEF to observe videoconferencing fatigue in the student population. First is the study of Oducado et al. (2021), which suggests that females, from lower year levels, with low academic performance, more gadgets, better videoconferencing attitudes, and those attending longer and more frequent virtual meetings exhibited higher levels of videoconferencing fatigue. Second is the work of Ebardo et al. (2021), which determined boredom, escapism, and information overload as predictors of videoconferencing fatigue. Third is the field experiment of Hezemans (2021), which noted zoom fatigue as a factor that influences certain aspects of group creativity among students. However, there is a dearth in the literature that examines the effect of videoconferencing fatigue on learning outcomes. An incidental qualitative finding by Cleofas (2021) shows that the energy-draining nature of synchronous videoconference-facilitated classes is a barrier to practicing self-care and engaging in online classes; however, this particular study did not make use of ZEF.

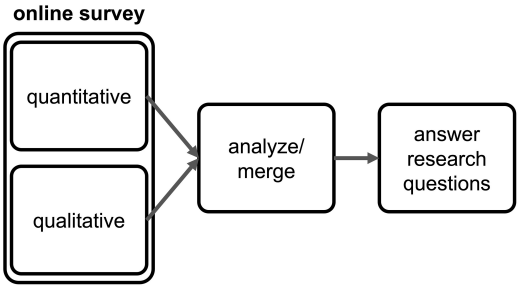

FIGURE 1
Convergent triangulation mixed methods design.

Research gaps and study objectives

Majority of studies that tackled videoconferencing fatigue examined it as an outcome variable. This present investigation contributes to the literature by exploring it as a phenomenon that can affect functional outcomes, specifically student engagement. Moreover, this study adds to the knowledge regarding videoconferencing fatigue in the school population by focusing on its prevalence and effects among senior high school students, in contrast to previous research that involved university students and general adults. Specifically, this present mixed methods study aims to address these gaps by addressing the following research objectives. This study aims to: (1) describe videoconferencing fatigue among senior high school students; (2) examine the relationship between videoconferencing fatigue and online student engagement.

Materials and methods

Study design and participants

This study made use of a concurrent triangulation mixed methods design. We adhered to GRAMMS (Good Reporting of a Mixed Methods Study; O'Cathain et al., 2008). In a triangulation mixed methods design, quantitative and qualitative data are collected and analyzed concurrently, with the intent to interrelate and identify possible discrepancies from both strands (Plano Clark et al., 2008). For the quantitative strand (QUAN), a cross-sectional approach was used, while for the qualitative strand (QUAL), a descriptive qualitative approach was utilized. In this study, QUAN and QUAL receive relatively equal weighting; both strands were emphasized in addressing the research objectives (Plano Clark et al., 2008). The mixed methods approach is visualized in **Figure 1**.

The present study's target population was the 2021–2022 batch of senior high school students (grades 11 and 12) from a selected private university in Manila, Philippines. Data were collected during the period when all classes in said university

were conducted purely online due to the COVID-19 pandemic, and all teachers and students made use of videoconferencing for academic purposes. Based on G*power analysis, a minimum of 74 respondents was needed for the total number of potential predictors (13 predictors, power = 0.95, p = 0.05). A total convenient sample of 215 students participated in our survey. One hundred percent completed the quantitative segments of the survey, while 153 (71.16%) answered the qualitative question in the form.

Instrumentation

The five-part online survey was created using *Google Forms* and collected quantitative and qualitative data. The first part determined the demographic profile of the respondents, which included the age, sex assigned at birth (coded 0 for females and 1 for males), grade level (11 or 12), and average monthly household income based on the brackets recommended by the Philippine Statistics Authority. The second section measured the respondents' digital use profile, which included the number of gadgets used, average internet speed at home [rated as generally slow (less than 4 Mbps), average (4 to 40 Mbps), and generally fast (greater than 40 Mbps)], the estimated number of videoconferencing days per week, and the number of videoconferencing hours in a day. Demographic and digital use profiles are included in the model to control for possible confounding effects.

The third part of the instrument is the Zoom *Exhaustion and Fatigue Scale* (ZEF) developed by Fauville et al. (2021a), which was used to quantify the level of videoconferencing fatigue of the students. ZEF is a 15-item questionnaire that covers the five dimensions of fatigue, which are general fatigue, visual fatigue, social fatigue, motivational fatigue, and emotional fatigue. Every domain was comprised of three items. Each item was answered via a five-point Likert scale (1 = not at all, 5 = extremely). A sample question is, "How mentally drained do you feel after video conferencing?" Cronbach's alpha for each domain was above 0.8, indicating acceptable scale reliability (Fauville et al., 2021a). For this study, no modifications were made to the ZEF scale when it was administered. In our sample, the overall Cronbach alpha score of the ZEF scale was 0.895 and ranged from 0.716 to 0.891 per domain.

The fourth part of the survey is the *Online Student Engagement Scale* (OSE) created by Dixson (2015), which was used to quantitatively measure students' engagement during online classes. OSE is a 19-item scale that measures skills (5 items), emotion (5 items), participation (6 items), and performance (3 items) related to online student engagement. Each item was also answered via a five-point Likert scale (1 = not at all characteristic of me, 5 = very characteristic of me). An example item statement is, "I take notes during presentations and video lectures." The overall scale demonstrated adequate reliability (Cronbach's alpha > 0.80; Dixson, 2015). In our sample, the Cronbach alpha score of the OSE scale was 0.909 and ranged from 0.767 to 0.812 per domain. For our study, OSE is treated as a composite, unidimensional construct.

The final section of the online survey is an open-ended question: "*How does videoconferencing affect your engagement in school?*" The students were afforded an unlimited textbox where they could type their answers as liberally as they could. The narratives collected from this question were used in the qualitative strand of the study. This process of using self-administered and survey-facilitated open-ended questioning has been used by recent empirical studies using qualitative approaches in both mono-method (Knudsen et al., 2021) and multi-method designs (Cleofas, 2022). Open-ended surveys are also appropriate for qualitative designs that lean toward basic perspective-focused and descriptive approaches (as opposed to experiential, interpretive, or reflective approaches) and for non-vocalized texts treated with qualitative content analysis (Hsieh and Shannon, 2005; Elo and Kyngäs, 2008).

Data collection procedure and ethical considerations

Our research procedure adhered to the principles of the Declaration of Helsinki. After the protocol of the study was granted ethical clearance by the De La Salle University Integrated School, we secured the parental consent of the SHS students with the assistance of point persons from different SHS sections via online correspondence. For students whose parents had signified consent, the online survey link was sent via email and/or social media private messaging. The survey was active during the whole month of November 2021. Informed assent was digitally secured using the first page of the survey. All collected data were stored in an encrypted cloud accessible only to the research team. Minimal risk is identified for this study, specifically a low probability of mild psychological distress. To address this, we provided our contacts in the survey form and encouraged respondents to contact us for any unpleasant psychological reactions while answering the test. These students would be referred to qualified psychological health professionals provided by the school. Throughout the duration of this study, no untoward incidents were noted, and no respondents required psychological services.

Data analysis procedure

For the quantitative data, frequency, percentage, mean and standard deviation were used to describe the key variables. To determine the level of videoconferencing fatigue and online student engagement, the means were interpreted as low (1.00–2.33), moderate (2.34–3.67), and high (3.68–5.00). The

domains of videoconferencing fatigue and the demographic and digital use profiles were then tested for correlation with OSE using bivariate statistics (Pearson R for continuous variables, independent *t*-test for dichotomous, and one-way ANOVA for multichotomous). The significant correlates were then included in the multiple regression model for the significant predictors of OSE. Kolmogorov–Smirnov results were non-significant, denoting normality of the distribution. Significance was set at $p < 0.05$. JASP version 0.16 was used for the analyses.

Qualitative content analysis was used for the narratives ($n = 153$). For the first objective, the process was deductive since the themes were already pre-identified based on the literature and scale used (the five domains of videoconferencing). Deductive analysis aims to organize the emerging concepts and assign them to the domains (Hsieh and Shannon, 2005). For the second objective, the process was inductive, such as the themes were formed based on the emergent lower-level concepts gleaned from the narratives (Elo and Kyngäs, 2008). We arrived at three themes for objective number two.

Data from QUAN and QUAL were integrated using a simultaneous bidirectional strategy, wherein we went back and forth the data of both strands as they were being developed to see convergences and divergences to make the analysis more robust (Moseholm and Fetters, 2017). To ensure trustworthiness (Lincoln et al., 2018), we familiarized ourselves with the data by reading and rereading the transcripts. Regular meetings were held to arrive at a consensus on the data analysis. Findings were also peer-reviewed by an expert on online education. Another aspect of the methodology that affords more credibility is that qualitative data collection was via a self-administered online survey. The absence of the researcher may provide a sense of anonymity which can improve the honesty and authenticity of the shared narratives. Moreover, the survey method allowed more participants to engage, making the current sample size multiple times larger than what is usually expected from a mono-method qualitative study. This assured vetting and data thickness despite the lack of opportunities to probe. Finally, all analysis-related meetings were recorded and logged to serve as our audit trails.

Results

Quantitative strand: Descriptive statistics for videoconferencing fatigue, online student engagement, and other key variables

Table 1 presents the descriptive statistical results for the study's key variables that address the first objective. For the demographic profile, the majority of the respondents are 17 years old (mean age = 17 ± 0.809), females (73%), and grade 12 (53.5%). In terms of digital use profile, the majority of the students own three gadgets or more (50.2%; mean number of gadgets = 2.60 ± 0.692), have average Internet speeds of 4 to less than 4 Mbps (60.9%), spend 5.47 ± 1.09 days per week, and 7.20 ± 3.03 h per day in videoconferencing. As for videoconferencing fatigue, moderate levels were reported in terms of visual fatigue (3.34 ± 1.07), social fatigue (3.56 ± 1.08), and emotional fatigue (3.39 ± 1.05), and high levels of general fatigue (4.04 ± 0.712) and motivational fatigue (4.16 ± 0.772). Lastly, the students demonstrated moderate online student engagement (3.42 ± 0.642).

TABLE 1 Descriptive statistical results of key variables ($N = 215$).

Key variables	*n*/mean	%/SD
Demographic profile		
Age	17.00	0.809
Sex assigned at birth		
Male	58	27.0%
Female	157	73.0%
Grade level		
Grade 11	100	46.5%
Grade 12	115	53.5%
Digital use profile		
Number of gadgets owned	2.60	0.692
1–2 gadgets	107	49.8%
3 gadgets or more	108	50.2%
Speed of Internet subscription		
Greater than 40 Mbps (generally fast)	74	34.4%
4 to less than 40 Mbps (average)	131	60.9%
Less than 4 Mpbs (generally slow)	10	4.7%
Videoconferencing days per week	5.47	1.09
Videoconferencing hours per day	7.20	3.03
Videoconferencing fatigue [a]		
General fatigue	4.04	0.712
Visual fatigue	3.34	1.07
Social fatigue	3.56	1.08
Motivational fatigue	4.16	0.772
Emotional fatigue	3.39	1.05
Online student engagement [a]	3.42	0.642

[a]Low = 1.00–2.33; moderate = 2.34–3.67; high = 3.68–5.00.

Qualitative strand: Concepts depicting the dimensions of videoconferencing fatigue

Table 2 presents the overview of the qualitative findings of the study. This section presents the themes and concepts from the qualitative analysis that address the study's first objective.

TABLE 2 Overview of qualitative findings in the study.

	Research objective 1: To describe videoconferencing among senior high school students	Research objective 2: To examine the relationship between videoconferencing fatigue and online student engagement
Emergent Themes	1.1. General fatigue: energy drain causing a general sense of exhaustion	2.1. Lesser energy for academic tasks due to videoconferencing-induced exhaustion
	1.2. Visual fatigue: decreased eye health causing dizziness and loss of focus	2.2. Poor absorption of learning through videoconferencing compared to in-person classes
	1.3. Social fatigue: lack of energy for social interactions and dissatisfaction with online communication	2.3. Accepting videoconferencing as a necessary tool for education during the pandemic
	1.4. Motivational fatigue: decreased ability to focus and resilience to cope with challenges	
	1.5. Emotional fatigue: stress, anxiety, and moodiness	

Theme 1.1. General fatigue: Energy drain causing a general sense of exhaustion

Student respondents report ***being drained of energy*** because of long hours of videoconferencing for classes. R165 shares, "*I find it extremely draining, and that energy expenditure makes it challenging to actively participate in class and to do other school works after said videoconferencing*." Due to the depletion of physical energy because of videoconferencing, students feel a ***general sense of exhaustion*** regarding school and other aspects of their lives, causing them to need more periods of rest across the day. R012 mentions, "*I find that I tend to take naps more often because of my exhaustion . . . I end up having the energy to do schoolwork late in the evening, too early in the morning.*"

Theme 1.2. Visual fatigue: Decreased eye health causing dizziness and loss of focus

The students have also noted a videoconferencing-induced decline in eye function. They noticed symptoms of ***decreased eye health***, such as pain. R169 writes, "*. . .There was a time when my eyes began to hurt. And it really stresses me out. . ..*" Another indicator of constrained vision they mentioned is ***dizziness and loss of focus***. Long periods of facing the monitor have made them feel lightheaded. R166 mentions, "*. . .it makes me dizzy because of radiation from the laptop and long hours of staring at it.*"

Theme 1.3. Social fatigue: Lack of energy for social interactions and dissatisfaction with online communication

Students also note that videoconferencing had detrimental impacts on their social well-being. Videoconferencing-induced exhaustion has caused students to ***lose energy for social interactions***. R064 mentions, "*videoconferencing has also made me want to be much more isolated compared to a face-to-face setup, and I'd rather sleep after class than talk to other people.*" Moreover, the students lament that they are ***dissatisfied with online communication***, claiming that it is less personal than in-person communication. R049 writes, "*. . .it is harder to initiate a conversation in a silent breakout room more than it is to do so when you are physically gathered up together in a small space . . ..*"

Theme 1.4. Motivational fatigue: Decreased ability to focus and resilience to cope with challenges

Respondents lament that long periods of videoconferencing have caused students to feel less motivated in academics because they claim that it induces ***decreased ability to focus on tasks***. For R036, the monotonous routine related to videoconferencing has reduced their motivation to engage in classes, declaring, "*It kind of lessens my motivation to study sometimes because it is the same thing every day and every week. You wake up, face the computer, try to study, leave the conference, then do other things.*" Moreover, this videoconferencing-induced demotivation has ***decreased students' resilience to cope with challenges***. R114 shares, "*I get really drained to the point that sometimes I don't want to do my requirements in advance.*"

Theme 1.5. Emotional fatigue: Stress, anxiety, and moodiness

Students express that videoconferencing has triggered various negative emotions. They share that videoconferencing complicates the ***stress and anxiety*** they already feel due to the difficulties of new normal learning. R022 mentions, "*. . .The online setup stresses me out more and takes a greater toll on my mental and emotional well-being.*" Moreover, students claim that videoconferencing enhances their ***moodiness***, especially when they are overwhelmed with other tasks. R102 aptly describes, "*videoconferencing generally makes me tired, irritable, and bored*."

Qualitative strand: Concepts depicting the dimensions of videoconferencing fatigue

This section presents the results from the inferential statistical analyses that address the study's second objective.

Bivariate results on the correlation of profile variable and videoconferencing fatigue with online student engagement

Table 3 shows the bivariate statistical results indicating significant correlations between independent variables of interest and online student engagement. Findings suggest that grade level (t = 2.25, p = 0.026), videoconferencing days per week (r = 0.560, $p < 0.001$), and visual fatigue (r = 0.187, p = 0.006) are significantly correlated with online student engagement. Higher online student engagement was observed among graduate students engaging in more videoconferencing days per week and having higher scores in visual fatigue.

Multiple regression results

Table 4 shows the results of the multiple regression test among the significant correlates and their predictive relationship with online student engagement. The overall model significantly predicts 9.74% of the variance of online student engagement (F = 7.59, $p < 0.001$). This means that the current model can explain approximately one-tenth of the variability of the online student engagement of the respondents. Findings suggest that students who spend more days a week in videoconferencing (B = 0.1304, p = 0.001) and have higher levels of visual fatigue (B = 0.0801, p = 0.043) have higher levels of online student engagement. Grade level no longer yielded significant results.

TABLE 3 Bivariate statistics on the correlation of demographic profile, digital use profile, and videoconferencing fatigue with online student engagement.

Variables	Mean (SD)	Test statistic	p-Value
Demographic profile			
Age[a]	–	−0.098	0.150
Sex assigned at birth[b]		1.94	0.053
Male	3.29 (0.741)		
Female	3.48 (0.596)		
Grade level[b]		2.25*	0.026
Grade 11	3.53 (0.665)		
Grade 12	3.33 (0.610)		
Digital use profile			
Number of gadgets owned[a]	–	0.115	0.091
Perceived internet speed[c]		1.28	0.295
Greater than 40 Mbps (generally fast)	3.52 (0.614)		
4 to less than 40 Mbps (average)	3.37 (0.642)		
Less than 4 Mpbs (generally slow)	3.41 (0.818)		
Videoconferencing days/week[a]	–	0.560***	< 0.001
Videoconferencing hours/day[a]	–	0.110	0.108
Videoconferencing fatigue[a]			
General fatigue	–	0.014	0.843
Visual fatigue	–	0.187**	0.006
Social fatigue	–	−0.075	0.276
Motivational fatigue	–	−0.101	0.140
Emotional fatigue	–	−0.041	0.555

Tests used: [a]Pearson R Correlation.
[b]Independent t-test.
[c]Oneway ANOVA.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Qualitative strand: Themes on the relationship between videoconferencing fatigue and online student engagement

This section presents the qualitative themes that address the study's second objective, as seen in Table 2.

Theme 2.1. Lesser energy for academic tasks due to videoconferencing-induced exhaustion

A major emerging pattern in the students' narrative responses demonstrates how videoconferencing takes away the energy that could be spent on performing academic tasks outside synchronous classes, hence decreasing their overall student engagement. R187 explains their shared experiences, "*After long hours doing videoconferencing, it is definitely physically and mentally draining for students to continue working after classes. . .. Moreover, they have to continue studying, doing classwork, and making group projects. . ..*" The sense of exhaustion after videoconferencing causes the need to increase rest periods, which consequently affects daily study habits. R028 writes, "*I become less enticed to do schoolwork in the afternoon, after my classes. I end up doing school mostly at night because videoconferencing drains me. . ..*" The students experience and understand the toll that long periods of videoconferencing while remaining sitting and sedentary can take on their health, which have negative consequences on their studies. R119 verbalizes, "*videoconferencing decreases my engagement in school as it is very tiring, and not being able to move around a lot irritates me.*"

Theme 2.2. Poor absorption of learning through videoconferencing compared to in-person classes

Many students claim that they learn less in classes delivered via videoconferencing. Their exhaustion can lead to a lack of focus when a synchronous online lecture is ongoing. R175 mentions, "*. . .it affects my focus as videoconferencing tends to make me feel tired and distracted sometimes. Thus, I would need to take a break from time to time to avoid spacing out.*"

TABLE 4 Multiple regression test of demographic, digital use, and videoconferencing fatigue determinants of online student engagement.

Variables	Estimate	SE	*t*	*p*-Value
Grade level (reference = Grade 11)				
Grade 12	−0.1258	0.0857	−1.47	0.143
Videoconferencing days per week	0.1304**	0.0396	3.30	0.001
Visual fatigue	0.0801*	0.0400	2.01	0.043

Model: $F = 7.59$, $R^2 = 0.0974$, and $p < 0.001$.
*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.

Contributing to the videoconferencing fatigue and hindrances in learning are the electronic issues that students encounter during classes, such as poor connectivity and loss of electricity. R016 narrates, "*Sometimes I feel like I'm behind my classmates . . . but there are times that there will be a brownout in our community that will make our WIFI unstable, so I'm having a hard time coping up with the lessons. . ..*" Resounding from the comments of the participants is the dissatisfaction they generally have with online-based learning and preference for in-person classes, which they claim would improve their learning and overall engagement. They lament the monotony of learning experiences because of the limited affordances provided by videoconferencing applications. They claim that they desire face-to-face interactions with teachers and classmates for a fuller learning experience. R158 writes, "*I feel like I am losing interest in actually studying and absorbing education. Human interaction and physical socialization are vital in ensuring that the school becomes a conducive place for learning, which videoconferencing cannot fully provide. . ..*"

Theme 2.3. Accepting videoconferencing as a necessary tool for education during the pandemic

Despite the reported disadvantages of videoconferencing, its resultant fatigue and its negative impact on student engagement in general, some of the students understand that in the context of the current pandemic, videoconferencing is an indispensable part of the educational experience that makes any form of student engagement in the new normal possible in the first place. R062 declares, "*It has helped in the continuance of my education. It is the closest experience we can have to a live interaction, even if it's just virtually.*" Despite being a less preferred medium for communication compared to in-person conversations, videoconferencing is the only way for them to have actual interactions with teachers and other students. R198 explains, "It's *currently our only choice for communicating and attending class, so we have no choice but to attend these meetings. It's not the best form of communicating, but at the very least, it gets the job done of conveying messages to each other, especially during classes.*" Some students also claim that there are unique advantages of videoconferencing, especially when used effectively by teachers. For instance, R184 writes, "It's *really helpful somehow; whenever a student is absent, they can just easily play the recorded meeting on zoom.*"

Integration of quantitative and qualitative findings

Students suffer from videoconferencing fatigue

In terms of the first objective of the present study, the pronounced extent of videoconferencing fatigue among the SHS students in the study is evinced by quantitative and qualitative findings. Quantitative results suggest that students have moderate (visual, social, and emotional) to high levels (general and motivational) of videoconferencing fatigue. Furthermore, qualitative findings demonstrate the various manifestations of how students experience each dimension of videoconferencing fatigue and how these affect not only their studies but also their health and social lives.

The relationship between videoconferencing fatigue and online student engagement is nuanced

For the study's second objective regarding the relationship between videoconferencing fatigue and online student engagement, the answer is not as straightforward as the first. From themes 2.1 and 2.2 that emerged from qualitative analysis, it can be gleaned that videoconferencing-induced exhaustion can deter student engagement. Specifically, long videoconferencing periods can deplete energy for academic-related tasks and decrease the absorption of learning. However, statistical findings from the regression model suggest that not all domains of videoconferencing are significant predictors of OSE, except for visual fatigue. Surprisingly, visual fatigue positively predicts OSE. This means that students endure visual fatigue from videoconferencing to engage in their online classes. This finding is corroborated by another significant quantitative positive predictor (videoconferencing days per week) and theme 2.3 from qualitative analysis. Student narratives reveal that they accept and understand that videoconferencing is a primary requirement to conduct online classes in the first place. Hence, to be meaningfully involved in online classes, they must attend videoconferencing many days a week despite experiencing increased visual fatigue. A fitting illustration for this ambivalent link between videoconferencing visual fatigue and online student engagement is a quote from R068: "Videoconferencing is going well with me, and I prefer it this way. However, it does put a toll on my health, mostly my eyes after hours on the screen."

Discussion

This convergent mixed methods study sought to describe videoconferencing fatigue and examine its relationship with

online student engagement among senior high school students during the second year of COVID-19 pandemic-induced online education in the Philippines. Theoretically, this study extends the literature on the effects of computer-mediated fatigue on functional outcomes, such as learning. Based on our knowledge, this is the first study that pursued a mixed methods approach to understanding the phenomenon of videoconferencing fatigue in education.

Consistent with previous research (Fauville et al., 2021a; Oducado et al., 2021), the quantitative findings of the present study indicate that students have moderate to high levels of videoconferencing fatigue. Among the five domains, general and motivational fatigue emerged as the highest scoring. Qualitative findings demonstrate specific manifestations of videoconferencing fatigue per domain contextualized to the participants' experiences as students. Our qualitative findings corroborate with the study of Nesher Shoshan and Wehrt (2021) among employees who also experienced various losses from videoconferencing. Many of the manifestations narratively reported by the students, such as a general sense of lack of energy, eye strain, dissatisfaction with interactional patterns, anxiety and moodiness, and decreasing motivation for tasks, had been demonstrated in a case study among college students and teachers (Massner, 2021).

Moreover, the quantitative and qualitative findings for the second research objective reveal the nuanced relationship between videoconferencing fatigue and online student engagement. On the one hand, qualitative analysis demonstrates how videoconferencing fatigue can constrain student engagement. Students report that videoconferencing takes away the energy they would have had for performing other academic tasks. This is confirmed by previous research that demonstrated videoconferencing-induced exhaustion due to online classes makes students demotivated in learning, unable to practice health-restoration activities, and dissatisfied with their academic performance (Cleofas, 2021). Moreover, qualitative results of the present study suggest that students engage poorly in videoconference-enabled classes because they have better learning absorption during face-to-face classes. Previous studies have likewise demonstrated that engagement in prolonged virtual meetings increases the longing to have in-person interactions with peers and colleagues (Nesher Shoshan and Wehrt, 2021). Moreover, evidence has already indicated that students reported declining overall online learning experience as the pandemic-induced remote education is prolonged (Maqableh and Alia, 2021).

On the other hand, our quantitative inferential results indicate that students with higher scores for online student engagement also exhibit higher levels of visual videoconferencing fatigue. This is surprising since previous evidence has linked poor grades to higher videoconferencing fatigue (Oducado et al., 2021). Another significant positive predictor of OSE is the number of days with videoconferencing per week, which runs parallel to findings of previous studies demonstrating that students and other school entities are involved in more online classes and tasks to perform well in school (Cleofas, 2021; Maqableh and Alia, 2021; Oducado et al., 2022). This means that students have to overuse their eyes to be able to attend more videoconferences to properly engage in online learning. Ophthalmology literature has noted the rise of cases of eye strain, dry eyes, and other vision problems during the COVID-19 pandemic because of the increased screen time individuals spend while on lockdown (Mohan et al., 2021; Prescott, 2021). This finding is supported by the last qualitative theme depicting the perceived necessity and salience of videoconferencing as an indispensable aspect of online classes. This seemingly implies that in pandemic-induced education, students have "no choice" but to participate in videoconference sessions, and experience the inconveniences of videoconferencing, just to continue learning, as demonstrated in previous research (Cleofas, 2021). However, evidence also suggests that despite the hardships students experience, some students can still have positive sentiments toward videoconference-facilitated classes, especially regarding their convenience and safety related to the threat of COVID-19 (Hussein et al., 2020; Maqableh and Alia, 2021) and with it a more satisfying online educational experience.

Conclusion

The present study signifies the presence of videoconferencing fatigue among SHS students who are involved in pure online classes during the COVID-19 pandemic. The insights from student narratives also highlight how videoconferencing fatigue is experienced in the specific context of online education. Moreover, findings suggest that students spend more days a week videoconferencing and endure visual fatigue to achieve optimum online student engagement. However, despite the perceived importance of videoconferencing for an online class, students also claim that the fatigue it causes can potentially decrease energy for the performance of academic tasks and absorption of learning, signifying the nuanced nature of the relationship between videoconferencing fatigue and online student engagement. Our study provides empirical evidence that despite their perceived negative impacts of videoconferencing, students had to tolerate visual videoconferencing fatigue to engage meaningfully in online classes.

Strengths and limitations of the study

The main strength of this study is its mixed methods design which provides deeper insights into the phenomenon

of videoconferencing fatigue in the context of online learning. However, we disclose some limitations of the study that can help temper the interpretation of our findings. First, the generalizability of the findings may be constrained since they were derived from a convenient sample from a single site. In addition, males were underrepresented in the sample. Moreover, our final model yielded a modest explanatory power; hence future studies may use more salient variables further to understand the relationship between videoconferencing fatigue and OSE. Also, since the qualitative data collection was done via survey instead of interviews, the chance to ask further questions to probe the responses could not be done. This inhibited a fuller realization of the credibility aspect of trustworthiness. Future researchers can consider more interpretive and reflective qualitative paradigms (e.g., phenomenology, narrative analysis) in exploring students' experiences in videoconferencing.

Implications and future studies

The results of the present study offer several implications for the stakeholders involved during pandemic-induced online learning among students. First, teachers and educational administrators should not make students sacrifice their overall eye health to participate meaningfully in online classes. Despite the indispensability of videoconferencing in delivering online education, faculty members can use non-videoconferencing based synchronous (e.g., real time chat-based discussions) and asynchronous strategies (e.g., pre-recorded lectures) to unburden the students with the cognitive and nonverbal overload they had to endure during videoconferencing. Administrators can continuously provide training and updates on emerging teaching strategies outside the realm of videoconferencing. Teachers should provide longer breaks between videoconferences to allow students to rest and regain their energy to engage meaningfully in other academic tasks. Faculty and school health personnel must provide eye health promotion information and programs. When in-person classes become feasible, school administrators must conduct eye assessments for all students to identify if they have experienced decline in vision.

Despite the lack of statistical significance between other domains of videoconferencing fatigue on student engagement, it must be noted the fatigue levels reported by the students are moderate to high, and student narratives demonstrate their negative effect on performance and knowledge acquisition. Hence, the promotion of the physical and mental health of the students must be sustained, especially during pandemic-induced online learning. Teachers and parents can be empowered to address the students' mental, physical, and visual health needs, during the period when online learning modality is needed to respond to public health crises like the COVID-19 pandemic. As societies and economies open as we enter a post-COVID world, educational policymakers must consider the gradual reopening of schools and in-classroom learning so that the use of videoconferencing tools will become more of an option than a daily necessity.

Future studies can consider the following foci to extend the insights found in this study. First is exploring potential mediators or moderators between videoconferencing fatigue, such as resilience, self-efficacy, and overall health, to address the uncanny relationship demonstrated by this present study. Second, videoconferencing fatigue can also be correlated with eye health and vision-related variables. Third is considering expanding the methods, like conducting longitudinal studies or sampling younger learners (elementary students), to ascertain whether videoconferencing fatigue and its relationship with OSE changes over time and with other age groups.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Integrated School, De La Salle University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

MD, JD, EO, and AP: conceptualizing, methodology, data gathering, and initial writeup. JC: conceptualizing, data analysis, and final writeup. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

Publisher's note

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Medical education during the coronavirus disease pandemic and students' mental health: A one-year follow-up

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Background: The coronavirus disease (COVID-19) pandemic has affected medical education and psychosomatic health of medical students. In this follow-up study, conducted 1 year after the transition to online learning (OL), we aimed to investigate changes in student mental health and identify factors associated with academic burnout and changes in medical education caused by the pandemic.

Materials and methods: This study compares the burnout rate and psychosomatic status (depression, anxiety, somatic symptoms) of medical students at Astana Medical University using an online questionnaire-based repeated cross-section design of the pre-pandemic period (September–November 2019), the initial period of the pandemic (April 2020), and the current study (March 9–30, 2021). In the pre-pandemic period, students studied only in a face-to-face format. Moreover, the current study (March, 2021) analyzed factors associated with academic burnout and changes in medical education caused by the pandemic. Statistical methods included mean comparison, frequency, and regression analysis.

Results: Data from a representative sample of undergraduate students were analyzed (n = 975, 58% of them participated in the previous study). The burnout rate was found to be lower compared with the period of traditional education (pre-COVID-19) and did not significantly differ from the initial period of the introduction of online learning (the initial period of the COVID-19 pandemic). The levels and prevalence of depression and anxiety also showed similar patterns. The prevalence of somatic symptoms has increased compared to the initial period of the pandemic, although it has not reached the level obtained in the pre-COVID-19 period. The negative changes caused by OL in medical education and learning effectiveness

have been associated with burnout. Factors associated with burnout, learning effectiveness, dissatisfaction with the quality of OL organization, and deterioration of medical education have been identified.

Conclusion: The medical education and mental health of medical students has undoubtedly undergone changes in the transition to OL due to the COVID-19 pandemic. Factors such as changing the content of education, the organization of the educational process and support from the school, the nature of student-teacher, student-school and student-student relationships, the possibility of mastering various skills and financial problems caused by the pandemic, played a significant role in the academic life of students. The results obtained have potential applications in organizing and improving the quality of continuing medical education in an era of global healthcare crises such as the COVID-19 pandemic.

KEYWORDS

COVID-19, medical education, medical students, mental health, burnout, online learning

Introduction

Relating to the coronavirus disease (COVID-19) pandemic, all medical schools moved to online learning (OL) format. The pandemic has led to unprecedented disruptions in medical training (Yuen and Xie, 2020). Given the low-quality evidence for OL efficacy in medical education (Kyaw et al., 2019) and the sudden enforced transition, medical students have had to adapt to OL in difficult situations. Moreover, it is known that the mental health status of medical students is already poorer than that of the general population, and academic stress is a major predictor, therefore such changes are likely to have a significant impact on these students (O'Byrne et al., 2021). It is also noted that high levels of perceived stress and burnout are inevitable during a pandemic, and OL can contribute to their strengthening (Silistraru et al., 2022).

The COVID-19 pandemic has exacerbated the mental health problems seen globally (Wu et al., 2021), including among medical students; the prevalence of depression, anxiety, and stress has increased during the pandemic (Huckins et al., 2020; Islam et al., 2020; Lyons et al., 2020; Saraswathi et al., 2020; Wang et al., 2020; Ihm et al., 2021; Li et al., 2021; Nikolis et al., 2021). There was a significant association between reporting stress and transition to OL and online assessment formatting. And those who reported that lower levels of stress are associated with an adequate response of the medical school to the crisis, shows the importance of medical school's programs to manage the COVID-19 pandemic-related changes in education (O'Byrne et al., 2021). The changes in the psychosomatic state of students during a pandemic may be caused by social distancing, self-isolation, financial hardship, academic delays, worry about family member's health, and social media exposure (Nurunnabi et al., 2021; Patwary et al., 2022).

In one of the studies in Cyprus, the authors argued that OL was associated with significant risks, namely the deterioration of mental health, and as a component of burnout, the level of cynicism increased due to the COVID-19 pandemic (Zis et al., 2021). Simultaneously, Lasheras et al. (2020) found no change in the prevalence of anxiety before and during the pandemic, although anxiety was correlated with COVID-19 stressors. Moreover, Pereira et al. (2022) resulted stability in medical students' mental health. A recent meta-analysis found a lower overall prevalence of student burnout during the COVID-19 pandemic (11.5%) compared to the overall prevalence of student burnout (12.2%) before the pandemic (Kaggwa et al., 2021). For instance, a study from Croatia indicates that the transition to OL did not affect the level of emotional burnout among medical students or their perception of their curriculum (Žuljević et al., 2021).

Previous research conducted in April 2020 indicated a decreasing prevalence and level of burnout, depression, anxiety, and somatic symptoms after transitioning to OL (Bolatov et al., 2021a). However, this study was conducted in the early stages of a pandemic and therefore has several limitations (Pereira et al., 2022). Moreover, there is a need for more information on the long-term effects of the COVID-19 pandemic on medical students and their education (Žuljević et al., 2021). In this regard, we aimed to investigate changes in students' mental health a year after the transition to OL and identify factors associated with academic burnout and changes in medical education caused by the pandemic.

Materials and methods

This study compares the burnout level and psychosomatic status of undergraduate medical students through a repeated cross-sectional design based on online questionnaire at Astana Medical University: Time 1 for pre-pandemic (September–November 2019), Time 2 for the initial period of pandemic (April 2020) (Bolatov et al., 2021a), and Time 3 for the current study (March 9–30, 2021). The study participants received invitations *via* the different "messenger" apps to complete an online survey created on the 1ka platform.[1] Participation in the study was voluntary and all students had the opportunity to get acquainted with the study aim and objectives. After reading the information about the study, students were asked to go to the next page, thereby expressing their informed consent to participation. By blocking repeated IP addresses, the study was protected from duplicate responses.

At the time of the study (Time 3), 3,989 undergraduates (1–5-year of study) were learning at the university. During the study, we received answers from 1,419 students, among whom 975 completed the survey (response rate = 68.7%).

On average, respondents spent 18 min on a survey that included the following tools and measures:

- Sociodemographic data: sex, age, year of study, living conditions, part-time job (medical and non-medical), volunteering associated with COVID-19, diagnosis of COVID-19, and participation in a previous study conducted in April 2020.
- Questionnaire regarding variables related to education during the COVID-19 pandemic: satisfaction with online learning (OL) format, attitudes of students toward training during a pandemic, and changes in learning associated with the transition to OL. Satisfaction with the quality of the OL organization was assessed using a 5-point Likert type scale; the responses "Dissatisfied" and "Very dissatisfied" indicated dissatisfaction. Students' attitudes toward OL were assessed using a 5-point Likert type scale; the responses "Agree" and "Strongly agree" indicated agreement. The change in learning associated with the transition to OL and deterioration in learning efficiency was assessed using a 5-point Likert scale; the responses "Deterioration" and "Considerable deterioration" were used to determine negative changes.
- Fear of COVID-19: Fear of COVID-19 was assessed using a 3-item adapted Snell's questionnaire (Snell's questionnaire regarding fear of AIDS) (Snell and Finney, 1998; Bolatov et al., 2021a). The questionnaire included the following: "Thinking about COVID-19 makes me feel anxious"; "I feel tense when I think about the threat of COVID-19"; and "I feel quite anxious about the possibility of another outbreak of COVID-19." Each question had five possible answers and ratings ranging from 1 (not at all) to 5 (very).
- Academic burnout: The Copenhagen Burnout Inventory developed by Kristensen et al. (2005), adapted for students by Campos, Carlotto, and Maroco (CBI-S) (Campos et al., 2013), and translated and validated by authors (Bolatov et al., 2021b) with a cut-off point of >50 (Borritz et al., 2006), was used to assess burnout syndrome. A feature of this scale is the measurement of exhaustion in four life-domains: Personal Burnout (PB), Studies-related Burnout (SRB), Colleague-related Burnout (CRB), and Teacher-related Burnout (TRB).
- Psychosomatic state: The Patient Health Questionnaire-9 (PHQ-9) contains nine items and assesses symptoms of depression based on symptoms over a 2-week period. The total PHQ-9 score ranges from 0 to 27 (Kroenke and Spitzer, 2002). The Generalized Anxiety Disorder 7-item scale (GAD-7) was used to assess anxiety symptoms, with total scores ranging from 0 to 21 (Spitzer et al., 2006). Somatic symptoms were investigated using the Patient Health Questionnaire-15 (PHQ-15), which consists of 15 somatic symptoms with scores ranging from 0 to 30 (Kroenke et al., 2002). Higher scores on these scales reflect higher severity levels of depressive symptoms, anxiety, and somatic symptoms, respectively, with a cutoff point of >10 (Kroenke et al., 2010). Translated versions of the PHQ-9, GAD-7, and PHQ-15 scales were obtained from the www.phqscreeners.com.

Sociodemographic data and respondents' answers on the CBI-S, PHQ-9, GAD-7, and PHQ-15 scales were collected at all time intervals (Time 1–3), while fear of COVID-19 was assessed only during the initial period of the pandemic (Time 2) and in the current study (Time 3). Internal consistencies of the scales at Time 3 were reliable to excellent: Cronbach's α for fear of COVID-19 (0.886), CBI-S (0.939), PHQ-9 (0.906), GAD-7 (0.924), and PHQ-15 (0.881) (Taber, 2018).

Statistical analysis was performed using IBM SPSS Statistics 20.0 and Jamovi version 1.6.16.0. Statistics included descriptive methods [frequency, means (M), and standard deviations (SD)], comparative analysis using the *t*-test or ANOVA with the Bonferroni *post-hoc* test (when more than two groups were compared, e.g., any scale in three times), frequency analysis, and determination of independent associations between variables using chi-square and regression analysis. A mediation model was applied to explore the pathway from dissatisfaction with the quality of OL organization *via* different factors related to OL to

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academic burnout. The level of statistical significance adopted was 5% ($p < 0.05$).

Results

A representative sample of 975 respondents was obtained; among them, 569 (58.5%) participated in the previous study (Time 2). Sociodemographic characteristics of the study population are presented in Table 1. The study included 753 (77.2%) female students and 222 (22.8%) male students. The average age was 19.9 (SD = 1.94).

The overall prevalence of burnout was 15.3%: PB (40.2%), SRB (40.0%), CRB (11.2%), and TRB (17.4%), with average scores 43.1 (SD = 21.9) for PB, SRB – 43.5 (SD = 22.3), CRB – 20.0 (SD = 21.4), TRB – 25.1 (SD = 21.8), and 32.9 (SD = 31.4) for CBI. There were no significant gender and academic year differences in burnout prevalence; however, females had 1.288 times more often PB and 1.302 times more often SRB ($p < 0.05$) than male students. The prevalence of burnout in the three time periods with distributions by burnout dimensions, year of study, and sex are illustrated in Figure 1.

The burnout rate did not depend on living conditions; however, respondents living alone (M = 33.3, SD = 33.9) demonstrated a higher level of CRB than those who lived with their parents (M = 19.7, SD = 21.1) or friends (M = 15.1, SD = 12.7), $p < 0.05$. Non-medical part-time job students showed higher level of burnout in all dimensions compared to students with no job: CBI (39.8 vs. 31.0), PB (49.1 vs. 41.2), SRB (50.7 vs. 41.5), CRB (26.9 vs. 18.4), and TRB (32.2 vs. 23.0), $p < 0.001$. Simultaneously, the level of burnout among participants with medical part-time jobs did not differ from that of the unemployed. Volunteering during the pandemic did not affect the level or prevalence of burnout. Confirmed and suspected diagnoses of COVID-19 were associated with PB in reference to not diagnosed (rate ratio = 1.545**; 1.281*), SRB (RR = 1.291*; 1.125), TRB (RR = 1.532*; 1.536*), and CBI (RR = 1.527*; 1.354), respectively (note: *, $p < 0.05$; **, $p < 0.001$).

TABLE 1 Sociodemographic characteristics of study population (N = 975).

Variable		N (%)
Sex	Male	222 (22.8)
	Female	753 (77.2)
Year of study	1	163 (16.7)
	2	205 (21.0)
	3	328 (33.6)
	4	205 (21.0)
	5	74 (7.6)
Lived	Alone	20 (2.1)
	With parents	733 (75.2)
	With own family	142 (14.6)
	With other relatives	48 (4.9)
	With friends	32 (3.3)
Part-time job	Healthcare organizations (COVID-19)	47 (4.8)
	Healthcare organizations (non-COVID-19)	74 (7.6)
	Non-medical	185 (19.0)
	No part-time job	669 (68.6)
Volunteering	Yes	107 (11.0)
	No	868 (89.0)
COVID-19 diagnosis	PCR and IgM/IgG positive or clinically confirmed	201 (20.6)
	Suspected (contact, asymptomatic)	346 (35.5)
	No diagnosis	428 (43.9)

The average PHQ-9 score at Time 3 was 7.56 (SD = 6.17). Compared to Time 3 at Time 1, the PHQ-9 level was 10.46 (SD = 6.76) and 7.13 at Time 2 (SD = 5.96). *Post-hoc* tests revealed significant differences in PHQ-9 levels between Time 1 and Time 2 and Time 1 vs. Time 3 ($p < 0.001$). The prevalence of depression was 24.9%, according to severity, as follows: minimal, 37.0%; mild, 34.8%; moderate, 14.7%; moderately severe, 7.3%; and severe, 6.2%. The mean value of the PHQ-9 at Time 3 was higher among female students (M = 7.88, SD = 6.28) than among males (M = 6.45, SD = 5.67), $p < 0.05$.

GAD-7 average value at Time 1 was 7.80 (SD = 5.93), 4.78 at Time 2 (SD = 4.99), and 5.33 at Time 3 (SD = 5.19). *Post-hoc* tests revealed significant differences in GAD-7 levels between Time 1 and Time 2 and Time 1 vs. Time 3 ($p < 0.001$). In this study, the prevalence of anxiety was 15.1% and was distributed by severity as follows: minimal, 58.9%; mild, 26.05%; moderate, 9.0%; and severe, 6.05%. The mean value of GAD-7 at Time 3 was higher among female students (M = 5.60, SD = 5.23) than among male students (M = 4.44 SD = 4.94), $p < 0.05$.

The PHQ-15 scale average value in Time 1 was 11.75 (SD = 5.89), 5.41 at Time 2 (SD = 5.16), and 7.86 at Time 3 (SD = 5.72); *post-hoc* test revealed significant differences in all comparisons ($p < 0.001$). The mean value of GAD-7 at Time 3 was higher among female students (M = 8.52, SD = 5.68) than males (M = 5.62, SD = 5.28), $p < 0.001$. Moreover, somatic symptoms were more prevalent among females (33.2%) than that for males (16.7%) ($\chi 2 = 22.6$, $p < 0.001$).

Figure 2 demonstrated average values of PHQ-9, GAD-7, PHQ-15, and prevalence somatic symptoms.

The average value for fear of COVID-19 was 2.91 (SD = 1.25). Female students demonstrated higher levels of fear than males (M = 2.98, SD = 1.22 vs. M = 2.68, SD = 1.32, $p < 0.05$). Volunteering students (M = 3.22, SD = 1.30 vs. M = 2.87, SD = 1.23, $p < 0.05$) and those diagnosed with COVID-19 (M = 3.14, SD = 1.22 vs. M = 2.89, SD = 1.23, $p < 0.05$) had more pronounced fear. Of the respondents, 52.5% experienced fear of COVID-19. Moreover, the mean on the fear scale was higher at Time 3 than at Time 2 (M = 2.91, SD = 1.25

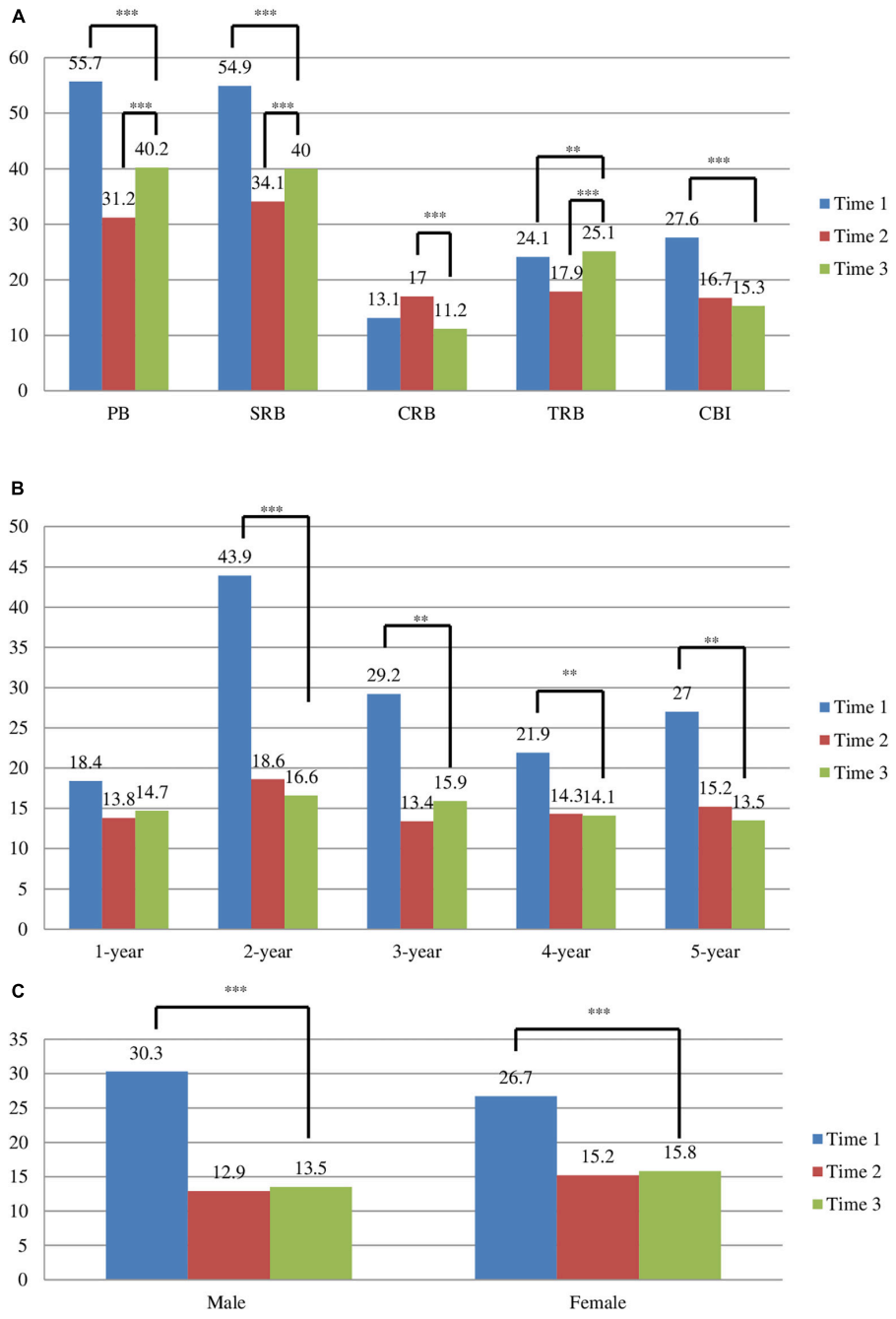

FIGURE 1
The prevalence of burnout and CBI mean scores before OL (Time 1), in initial period of online learning (OL) (Time 2) and after 1 year of OL (Time 3) caused by the COVID-19 pandemic distributed by: **(A)** CBI dimensions; **(B)** years of study; **(C)** gender. Data on burnout prevalence in Time 1 and Time 2 based on previous research (Bolatov et al., 2021a). $^{**}p < 0.05$, $^{***}p < 0.001$.

vs. $M = 2.61$, SD = 1.25, $p < 0.001$). The correlations among the main indicators used in this study are presented in **Table 2**.

Of the students, 719 (73.7%) were satisfied with their academic performance. Students were asked, "How has your academic performance changed after switching to online learning?" The responses were as follows. Of the students, 348 (35.7%) indicated that their academic performance improved after switching to OL; 167 (17.1%) noted deterioration, and 460 (47.2%) did not change. Among those who indicated that the transition to OL improved their academic performance, 256 (73.5%) indicated that their studying improved during the OL period; 26 (7.5%) responded that improvements in academic

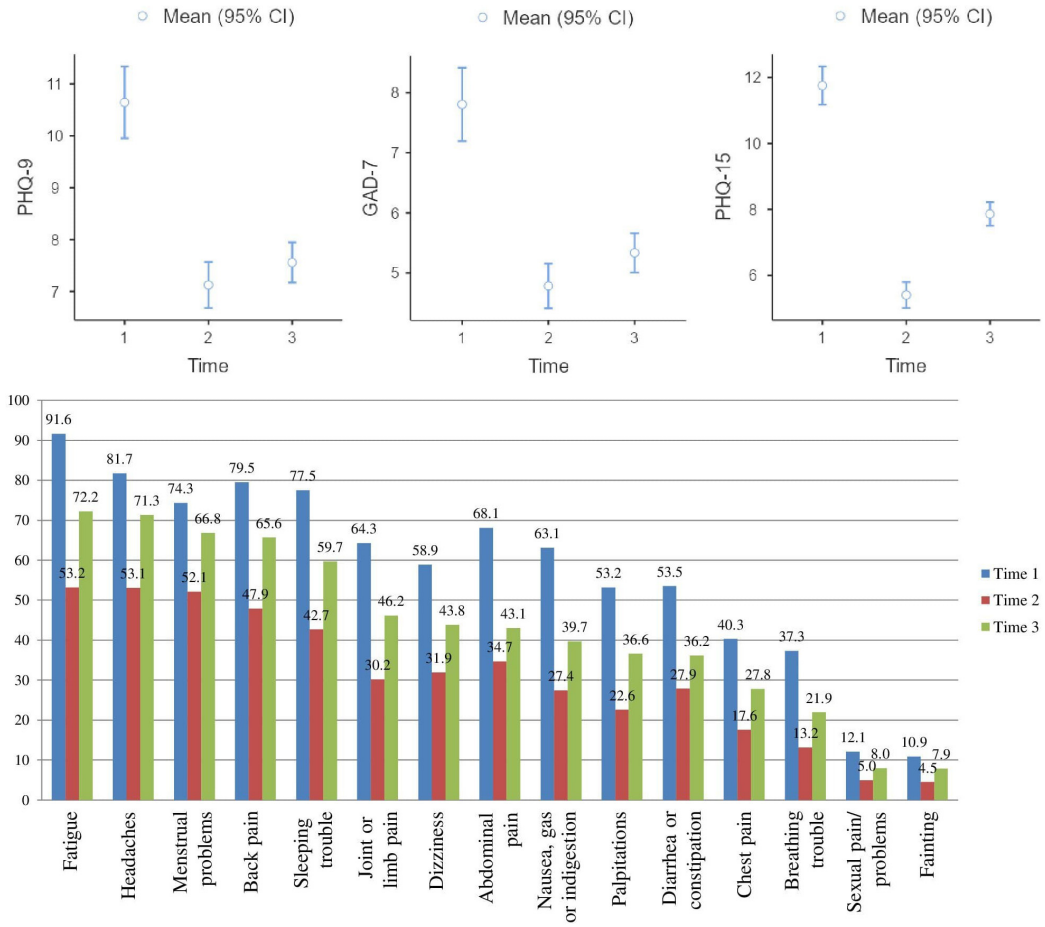

FIGURE 2
Average values in PHQ-9, GAD-7, and PHQ-15 scale, and prevalence of somatic symptoms in Time 1, 2, and 3.

TABLE 2 Correlation of study main indicators (N = 975).

	M (S.D)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) PB	43.1 (21.9)	–							
(2) SRB	43.5 (22.3)	0.708**	–						
(3) CRB	20.0 (21.4)	0.310**	0.432**	–					
(4) TRB	25.1 (21.8)	0.449**	0.597**	0.492**	–				
(5) CBI	32.9 (17.4)	0.797**	0.864**	0.718**	0.798**	–			
(6) Fear of COVID-19	2.91 (1.25)	0.164**	0.051	−0.015	−0.033	0.053	–		
(7) PHQ-9	7.56 (6.17)	0.738**	0.680**	0.408**	0.476**	0.725**	0.036	–	
(8) GAD-7	5.33 (5.19)	0.676**	0.632**	0.392**	0.452**	0.678**	0.094**	0.817**	–
(9) PHQ-15	7.86 (5.72)	0.599**	0.547**	0.369**	0.442**	0.617**	0.070**	0.653**	0.640**

*$p < 0.05$, **$p < 0.001$.

performance were associated with higher scores during OL compared with TL; 35 (10.1%) indicated both reasons; and 31 (8.9%) did not indicate either. Students who responded that their academic performance deteriorated with the transition to OL indicated the following reasons: 70 (41.9%) found their studies worsened, 49 (29.3%) felt teachers began giving lower grades, 22 (13.2%) indicated both reasons, and 26 (15.6%) did not indicate either. Of the participants, 378 (38.8%) experienced OL difficulties. Of the students, 736 (75.5%) indicated that they were satisfied with the quality of the OL organization. Dissatisfaction with academic performance and OL quality were associated with burnout (RR = 2.06 and 1.83, respectively;

$p \leq 0.001$), while dissatisfaction with academic performance was associated with depression (RR = 1.16, $p < 0.05$). However, changes in academic performance were not found to be associated with burnout, depression, or anxiety. However, any change in academic performance, such as deterioration (RR = 1.57) or improvement (RR = 1.75), was significantly associated with TRB ($p < 0.05$).

Table 3 presents data on students' agreement with certain statements according to the OL during the COVID-19 pandemic, as well as their relationship with burnout and dissatisfaction with the quality of the OL organization, calculated using regression analysis. Examining these items as mediators between OL dissatisfaction and burnout (**Figure 3**), Items 1 and 8 showed statistically significant effects at a level of $p < 0.001$.

The changes associated with the transition to OL due to the COVID-19 pandemic and the association of deterioration with burnout and dissatisfaction are presented in **Table 4**. Deterioration in medical education and learning efficiency caused by OL were positively associated with academic burnout (OR = 1.85 and 1.58, respectively) and dissatisfaction with the quality of training organization (OR = 5.61 and 5.86, respectively; $p < 0.001$).

Cronbach's α values for the items in **Tables 3**, **4** were 0.744 and 0.938, respectively. The "good" to "excellent" levels of internal consistency (Borritz et al., 2006) of the questions from **Tables 3**, **4** makes it possible to consider them scales for assessing students' attitudes toward online learning and changes in learning associated with the transition to OL.

Of the students, 388 (39.8%) indicated that, due to the COVID-19 pandemic, they decided to become healthcare workers to a greater extent, while 48 (4.9%) indicated that they wanted to leave the healthcare system; 539 (55.3%) indicated that the pandemic did not affect their choice of profession. Students who indicated that they changed their minds to be healthcare workers were 2.2 times more likely to experience burnout than students whose choice had not changed ($p < 0.05$) and 2.6 times more likely to burn out than students who strengthened their preferences in the profession due to the pandemic ($p < 0.001$). Respondents who indicated that they made a convincing decision to become healthcare workers ($M = 3.12$, SD = 1.29) had a higher level of fear of COVID-19 than those who were uninfluenced by the pandemic in their career choices ($M = 2.78$, SD = 1.19), $p < 0.001$.

Discussion

At the time of the current study, over a year has passed since medical students switched to OL due to the COVID-19 pandemic. Previous research has shown that with the transition to OL, the psychosomatic state of medical students in Kazakhstan improved, and the level of academic burnout decreased (Bolatov et al., 2021a). However, these results were obtained in the early period, almost immediately after entering a new type of distance education, especially for undergraduate students and their educators, as distance education was previously practiced in post-graduate and refresher courses. It was assumed that such positive changes were initially associated with the period of adaptation and the disorganization of the university's online educational services. The workload on the teaching staff has especially increased, as follows: (1) adaptation to new methods of teaching and assessing students, (2) mastering electronic gadgets, (3) increasing the scope of checking written works and constantly checking them for anti-plagiarism, (4) the severity of evaluating practical and communication skills, and (5), because some teachers joined the front line in the fight against COVID-19, the hourly workload on the remaining teachers increased (Johnson and Coleman, 2021; Lizana et al., 2021; Billett et al., 2022; Răducu and Stanculescu, 2022; Westphal et al., 2022; Klusmann et al., 2023). On the other hand, stressors were also observed among students through (1) buying the necessary gadgets to participate in classes and (2) adapting to new learning environments and technologies (O'Byrne et al., 2021). Perhaps in the initial period of the immediate introduction of OL, such stressors could be mitigated by certain adversaries on the part of the university administration in the control of education; however, after the renewal of all educational technologies, such stressors did not cease to affect the student-teacher relationship. Because the era of pandemics tends to repeat itself over time, it is imperative to create an educational system that is safe and sustainable in the long term (Althwanay et al., 2020). Thus, the authors conducted a repeated study after 1 year to assess the psychosomatic state of students and identify the relationship between these indicators and the main components of OL and changes associated with this transition.

Thus, in the course of the repeated study, it was found that, regardless of the academic year and gender, the overall prevalence and level of academic burnout, depression and anxiety were significantly lower than during the period of TL, and remained approximately at the same level as in the initial period of transition to OL. It was also found that academic burnout was associated with the diagnosis and fear of COVID-19, adaptation to the OL format, living conditions, and the presence and nature of additional work during the pandemic. At the same time, the observed increase in somatic symptoms a year after the onset of the pandemic was most likely associated with the long-term consequences of the new format of learning and life in general.

Medical education has undoubtedly undergone changes during the transition to OL due to the pandemic, and factors

TABLE 3 The degree of students' agreement with statements about OL during the COVID-19 pandemic and their association with burnout, dissatisfaction with the quality of OL organization, and deterioration in medical education and learning efficiency on linear regression analysis (N = 975).

#	Item	Agreement n (%)	PB (R^2 = 0.118)	SRB (R^2 = 0.190)	CRB (R^2 = 0.083)	TRB (R^2 = 0.193)	CBI (R^2 = 0.210)	Dissatisfaction with the quality of OL organization (R^2 = 0.304)	Deterioration in medical education (R^2 = 0.433)	Deterioration in learning efficiency (R^2 = 0.463)
1	I believe that our university is doing everything it can to help students adapt to OL during a pandemic	650 (66.7)	−0.197**	−0.335**	−0.259**	−0.368**	−0.365**	−0.385**	−0.186**	−0.143**
2	OL is a more comfortable way of learning for me	494 (50.7)	0.134*	0.157**	0.039	0.139**	0.148**	−0.123*	−0.321**	−0.315**
3	During the OL period, I began to study more on my own	701 (71.9)	−0.034	−0.083*	0.075	−0.038	−0.026	−0.005	−0.235**	−0.245**
4	Buying the necessary gadgets (computer, phone, webcam, etc.) to participate in OL has become an additional burden for me and my family	351 (36.0)	0.031	0.067*	0.008	0.127**	0.071*	0.092*	0.054*	0.064*
5	Checking work for anti-plagiarism in OL increased my adherence to the rules of academic honesty	719 (73.7)	−0.067*	−0.024	−0.050	−0.106**	−0.078*	−0.077*	−0.037	−0.037
6	The absence of the need to change campuses and the training bases (moving from one building to another, from one clinical base to another) made my life easier	613 (62.9)	0.134**	0.089*	0.008	0.063	0.093*	−0.015	−0.030	−0.101**
7	One of the positive features of OL is the ability to spend less money on additional food, travel, and housing	824 (84.5)	0.017	0.032	0.025	0.055	0.040	−0.012	−0.004	0.027
8	With the transition to OL, I began to feel lonely	306 (31.4)	0.172**	0.142**	0.065	0.070	0.142**	0.076*	0.013	0.013
9	With the transition to OL, I began procrastinating more often	299 (30.7)	0.125**	0.134**	0.087*	0.082*	0.135**	0.052	0.037	0.081*

*$p < 0.05$, **$p < 0.001$.

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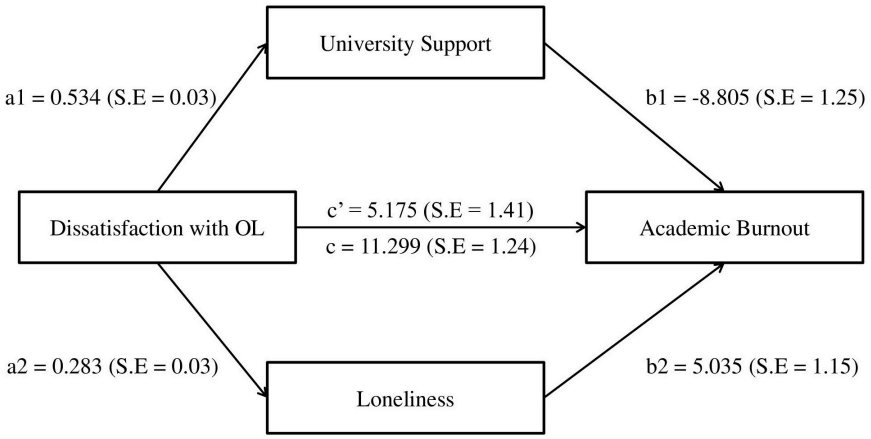

FIGURE 3
Mediating effect of university support and loneliness in the relation between dissatisfaction with OL and academic burnout (N = 975) during the COVID-19 pandemic. Note: all significance level at $p < 0.001$; all presented effects are unstandardized; a1 – the effect of dissatisfaction with OL on university support; b1 – the effect of academic life satisfaction on academic burnout; a2 – the effect of dissatisfaction with OL on loneliness; b2 – the effect of loneliness on academic burnout; c' is the direct effect of dissatisfaction with OL on academic burnout, and c is the total effect of dissatisfaction with OL on academic burnout.

TABLE 4 Changes associated with the transition to OL during the COVID-19 pandemic and the association of deterioration with burnout, dissatisfaction with the quality of OL organization, and deterioration in medical education and learning efficiency on log-linear regression analysis (N = 975).

#	Item	Deterioration *n* (%)	PB	SRB	CRB	TRB	CBI	Dissatisfaction with the quality of OL organization	Deterioration in medical education	Deterioration in learning efficiency
1	With the transition to OL, my opportunities to master the competencies or skills necessary in the future.	330 (33.8)	1.81**	1.90**	1.31	1.56 *	1.48 *	4.95**	1.55**	1.49**
2	During the period of OL, my communication with teachers.	113 (11.6)	1.48*	2.15**	2.15*	3.24**	3.26**	5.35**	1.46**	1.44**
3	During the period of OL, my communication with fellow students.	164 (16.8)	1.57*	2.34**	2.84**	2.25**	2.91**	3.91**	1.34**	1.35**
4	With the introduction of OL, the system for assessing my knowledge.	173 (17.7)	1.56*	2.97**	2.62**	2.78**	2.67**	7.21**	1.49**	1.49**
5	During the OL period, my focus on my studies.	241 (24.7)	1.76**	2.34**	1.59*	1.54*	1.81*	5.86**	1.52**	1.59**
6	With the introduction of OL, my opportunity to fully master practical skills.	404 (41.4)	1.84**	2.27**	1.39	1.57*	1.80**	5.29**	1.37**	1.40**
7	During OL, feedback from teachers.	199 (20.4)	2.06*	3.09**	2.46**	4.19**	2.29**	9.21**	1.36**	1.40**
8	During the period of OL, communication with the dean's office.	109 (11.2)	1.47*	2.16**	3.15**	3.79**	2.96**	7.40**	1.33**	1.35**
9	Due to the transition to OL, my communication skills.	208 (21.3)	1.79**	2.71**	2.09**	1.97**	2.39**	5.71**	1.37**	1.41**

*$p < 0.05$, **$p < 0.001$.

such as changes in the content of education, the organization of the educational process and support from the school, the nature of student-teacher, student-school and student-student relationships, the availability of clinical practice and financial problems caused by the pandemic played a significant role in the academic life of students.

Coronavirus disease-caused online learning and academic burnout

The overall prevalence of burnout was 15.3%, which was significantly lower than that during the period of traditional learning (TL, Time 1) and approximately at the same level as the initial period of transition to OL (Time 2). This pattern was observed regardless of school year and gender and was also seen when comparing the mean values on the CBI scale (M = 32.9, SD = 31.4 in Time 3 vs. M = 39.77**, S. D. = 17.98 at Time 1 and M = 32.65, SD = 17.64 in Time 2). In comparison, Zis et al. (2021) showed that burnout prevalence did not differ significantly between the pre-COVID-19 and COVID-19 periods; however, it dropped in Year 4 but increased in Year 6.

The prevalence of PB, SRB, and TRB at Time 3 (after 1 year of OL) was lower than that at Time 1 but higher than that at Time 2; however, this pattern in the average level of burnout was significant only for PB (M = 43.1, SD = 21.9 in Time 3 vs. M = 38.46, SD = 21.16 in Time 2, $p < 0.001$). Such changes in PB can be attributed to the pandemic's overall impact on student well-being. This was confirmed by the presence of a positive correlation between burnout and fear of COVID-19, while other burnout dimensions were not significantly correlated (**Table 2**). Moreover, a diagnosis of COVID-19 is positively associated with burnout. The increase in the prevalence of SRBs and TRBs (**Figure 1**) can be explained by the adaptability of teachers and the education quality control system a year after the transition to OL. The situation differs from CRB, which increased at Time 2 compared to Time 1 but decreased at Time 3 (**Figure 1**). This indicates that, over time, students have been able to learn how to communicate and work together on online platforms.

The burnout rate did not depend on the living conditions. However, students living alone experienced more pronounced CRB than those living with their parents or friends. Although Wong et al. (2020) indicated that there were few such students (n = 20) requiring additional support from the family and the university, living alone was associated with increased loneliness. Of the respondents, 31.4% indicated that with the transition to OL, they began to feel lonely, and this feeling was positively associated with burnout and dissatisfaction with OL (**Table 3**).

Because employed students must combine work and study, they are more susceptible to various stress effects and burnout (Yang, 2004; Perna, 2010). Current research reveals that students with non-medical part-time jobs showed higher levels of burnout than did unemployed students without any job. At the same time, the level of burnout among participants with medical part-time jobs (COVID-19-related or non-COVID-19) did not differ from those unemployed. In an earlier study prior to the COVID-19 pandemic, it was found that working part-time students have a higher level of PB (unpublished) regardless of the work. Perhaps working in the medical field during the COVID-19 health crisis had a positive effect on professional identity and did not contribute to depersonalization or a decrease in personal achievements. Moreover, altruistic behaviors such as volunteering during the pandemic did not affect the level and prevalence of burnout.

Coronavirus disease-caused online learning and mental health

The levels of depression and anxiety on the PHQ-9 and GAD-7 scales, respectively, were lower than in the period before the pandemic and did not significantly differ from the initial period of the pandemic. The prevalence of depression and anxiety was 24.9 and 15.1%, respectively. These indicators were significantly lower than those in the pre-COVID-19 period ($p < 0.001$) and were not significantly different from those in the initial period of the pandemic (Bolatov et al., 2021a). A study conducted among US medical students showed that, compared to previous data during the COVID-19 era, anxiety and depression were 61 and 70% higher, respectively (Halperin et al., 2021). In comparison, a prospective study from Brazil showed stability in the medical students' mental health (Pereira et al., 2022).

Based on the PHQ-15 scale, the severity of somatic symptoms was lower than that in the pre-COVID-19 period but increased after 1 year of OL. The prevalence of all somatic symptoms increased compared with the data obtained during the initial period of the pandemic. This is most likely because of the long-term impact of the pandemic on students' lives. Harries et al. (2021) indicated that pandemics had moderate effects on stress among medical students. Gica et al. (2020) reported increased psychosomatic symptom levels after the COVID-19 outbreak compared to before.

Coronavirus disease-caused online learning and academic life

Three-quarters (75.5%) of respondents indicated that they were satisfied with the quality of the organization of the OL during the COVID-19 pandemic, and about the same (73.7%) were satisfied with academic performance, as it was higher than that in the OL initial period (Bolatov et al., 2021a). In this study (Time 3), over one-third (35.7%) of the respondents indicated an improvement in academic performance, most of whom (73.5%) attributed this to the fact that their studies improved after switching to OL. With the transition to OL, slightly more than half (51.1%) of the students indicated that the system of knowledge assessment did not change, and 17.7% indicated that it had

deteriorated, which was positively associated with burnout. Dissatisfaction with academic performance and the quality of OL organization is associated with burnout. A study conducted among Jordanian university students showed that 81.5% of the respondents agreed that using digital learning tools was responsible for low academic performance (Haider and Al-Salman, 2020).

Online learning requires students to have electronic devices, such as computers, laptops, and webcams. However, not all students were financially ready for the transition to OL, which contributed to certain financial problems in their acquisition, especially for bachelor's students who had no previous experience with the distance learning format. Thirty-six percent of study participants indicated that buying the necessary gadgets has become an additional burden for them and their families; this was positively associated with dissatisfaction with online learning and burnout, and, to a greater extent, with TRB, indicating 1.15 times more negative changes in education and 1.16 times more negative changes in study efficiency.

One of the main components of medical education is students' clinical practice. At the time of the study, Astana Medical University did not have its own university clinic, and students were trained at the bases of various medical institutions scattered throughout the city, which could lead to additional financial costs and wasting of students' personal time and, in turn, to stress. OL may remove such inconveniences; moreover, with the transition to OL, students have begun to spend less money on moving, renting an apartment, and eating. The cost savings associated with moving to OL were not associated with burnout or learning satisfaction. At the same time, the absence of the need to change the training corpus was positively associated with burnout, especially personal burnout. This can be explained by the negative impact of the lack of clinical practice. The above conditions created by the OL can potentially affect the comfort of learning. Half of the respondents (50.7%) indicated that OL was a more comfortable form of learning. While it was positively associated with OL satisfaction and reduced negative changes in medical education and study efficiency, it was also positively associated with burnout, especially SRBs and TRBs. Shreffler et al. (2020) recommended finding comfortable places to study to combat burnout, and Costa et al. (2012) found that students who felt uncomfortable with course activities experienced a high prevalence of burnout. However, our results indicate the opposite, most likely owing to the online form of education.

The lack of personal interaction with OL creates problems in the relationship between the student and the teacher (Wilson and Shankar, 2021). Of the respondents, 22.4% indicated that online learning worsened feedback from teachers; 16.8 and 11.6% noted weakened relationships with fellow students and with teachers, respectively; and 11.2% of students noted deterioration in feedback from the dean's office. These changes were strongly associated with burnout and deterioration of the effectiveness of learning and education.

Coronavirus disease-caused online learning and medical education

The COVID-19 pandemic has caused unprecedented disruption in medical education worldwide (Alsoufi et al., 2020). In this study, a quarter of the students indicated that their medical education deteriorated with the introduction of OL, which were 1.85 times more likely to experience burnout. The determinants of the deterioration in medical education are presented in **Tables 3**, **4**. With the transition to OL, students' opportunities to master the competencies or skills necessary in the professional future decreased, as indicated by a third of the respondents. To a lesser extent, deterioration affected communication skills (21.4%), and, to a greater extent, practical skills (41.5%). Regardless, any impairment in mastering the necessary skills was associated with burnout and deterioration in education, which can lead to problems in the professional development of students.

The higher the learning efficiency, the less time it takes for students to achieve competence (Bruce, 2004). With the transition to online learning, the learning efficiency did not change in 38.9%, improved in 38.3%, and worsened in 22.5% of students. The determinants of deterioration in learning efficiency are presented in **Tables 3**, **4**.

The rapid and unusual transition to OL requires support from the university. Social support is vital to students' mental health and should be effectively offered and carefully maintained during isolation and quarantine (Aristovnik et al., 2020). Two-thirds of the respondents believed that the university is doing everything it can to help students adapt to OL during a pandemic. University support was negatively associated with burnout and reduced the negative impact of COVID-19-caused OL on learning efficiency and medical education, as evidenced by its mediating role in the relationship between dissatisfaction with OL and academic burnout, while loneliness worsened it.

Coronavirus disease-caused online learning and academic integrity

The transition to OL helped strengthen the policy of academic integrity at medical universities in Kazakhstan. Before the pandemic, the threshold of permissible plagiarism was imposed only on post-graduates to write their theses; then, with the transition to the online format, additions were made for undergraduate students regardless of the form of work, especially for written controls. The syllabi of

the disciplines included items on observance of academic integrity, thresholds for plagiarism, and measures applied to violate these orders. Thus, 73.3% of the respondents indicated that checking their work for anti-plagiarism during OL enforced their adherence to the rules of academic honesty; such students were less likely to experience deterioration in their education. However, it negatively affected the student-teacher relationship and contributed to TRB. This can be explained by the fact that, starting from school education, students were not given such requirements; this practice only began to be introduced into the education system of Kazakhstan in recent years. During the OL period, the university purchased the programs on anti-plagiarism and proctoring in full, making it possible for Kazakhstan's higher educational institutions to move to a new level of academic policy and compliance with international educational standards.

Study limitation

This study has several limitations. First, it was not prospective; comparison at three time intervals was based on a repeated cross-sectional study of representative samples from the same population (medical students at Astana Medical University). Second, because the results were based on a cross-sectional design, it was not possible to identify causal relationships. Finally, the results couldn't be generalized as these studies were applied in only one institution.

Conclusion

A study conducted a year after the forced introduction of OL due to the COVID-19 pandemic showed the stability of the burnout and mental health of students compared with the initial period of the pandemic and confirmed that this intervention contributed to the improvement of the students' well-being compared to the pre-COVID-19 period, regardless of the pandemic's impact on students' academic life. However, there was a marked worsening of the somatic symptoms. This study identified factors associated with academic burnout during distance learning, including assessing the influence of sex, year of study, living conditions, job availability, student attitudes toward certain features of the online format, and changes associated with the transition to OL. Moreover, determinants of deterioration in medical education, effectiveness, and satisfaction during the OL period were identified. Thus, support from the school was negatively associated with the level of burnout and dissatisfaction with the online learning format. At the same time, the perceived comfort of the new learning format, loneliness and procrastination were positively associated with the level of burnout. And such deterioration in education caused by the pandemic, such as the possibility of mastering the necessary competencies, communication at various levels, and changes in the knowledge assessment system, were positively associated with the level of academic burnout, dissatisfaction with learning during the pandemic, and a general deterioration in medical education and learning efficiency. These results will improve the understanding of online teaching methods in medicine to take the necessary measures in organizing long-term education during crises, such as the COVID-19 pandemic.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the Astana Medical University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

AB, TS, and DP: conceptualization. TS and DP: methodology and supervision. AB and ED: formal analysis and investigation. AB: writing – original draft preparation. MZ, DS, and DP: writing – review and editing. All authors contributed to the article and approved the submitted version.

Conflict of interest

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

Publisher's note

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Digital competencies of Peruvian teachers in basic education

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Digital teaching competence is directly related to the knowledge, use of Information and Communication Technologies (ICTs). Its use in educational contexts and processes seeks to integrate technology and pedagogy. The objectives of this study are to evaluate the level of Digital Teaching Competencies (DTCs) possessed by basic education (BE) teachers in different Peruvian schools and their comparison by competency area, considering sociodemographic factors. The research responds to a quantitative methodological approach. A non-experimental design of a comparative descriptive type was used, and a non-probabilistic purposeful sampling was applied. A total of 3,142 BE teachers participated in the study, including the educational levels of preschool (0–5 years), primary school (6–11 years), and Secondary school (12–16 years), belonging to public institutions located in rural and urban areas of the province of Arequipa (Peru). The instrument developed in the European Framework of Digital Competence, DigCompEdu Check-In, was applied. This instrument aimed to measure teachers' level of competence in the digital domain. The main results show that a more significant number of teachers present an Integrator competence level (B1), followed by the Expert level (B2), and the Explorer level (A2). Furthermore, low percentages are observed in the most advanced leadership levels, Leader (C1) and Pioneer (C2), in the use of ICTs. The results obtained suggest implementing new strategies to improve DTCs. Based on critical conceptions, technology constitutes an essential tool for education in the twenty first century.

KEYWORDS

digital competence (DC), teaching, information and communication technologies-ICTs, basic education, DigCompEdu

Introduction

Within the framework of twenty-first century education, especially in the coronavirus pandemic context, all countries have experienced different changes at various levels of the education sector.

According to the Report of the Economic Commission for Latin America and the Caribbean and the Regional Office of Education for Latin America and the Caribbean of the United Nations for Educational, Scientific and Cultural Organization (Comisión Económica para América Latina y el Caribe [CEPAL], and Oficina Regional de Educación para América Latina y el Caribe de la Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura [OREALC/UNESCO], 2020), one of the measures adopted by the governments in the countries of this geographical area at the beginning of the pandemic, was the total suspension of attendance at all educational levels; later, most of these countries gradually returned to classes. According to this report, 29 Latin American countries opted for distance education, of which 18 chose different online education modalities through virtual asynchronous learning platforms; 4 chose live classes; likewise, 23 used radio and television as teaching aids (Comisión Económica para América Latina y el Caribe [CEPAL], and Oficina Regional de Educación para América Latina y el Caribe de la Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura [OREALC/UNESCO], 2020).

Another essential piece of information in this report revolves around digital divides. In particular, access to devices in homes presents a notorious inequality. The level of access to computers, internet access, and educational software are some indicators that show that Latin American countries were not prepared, except for countries like Chile and Uruguay and, in part, Brazil. In the Peruvian case, only 57% of school-age students had internet access, one of the lowest compared to other countries in the region (Comisión Económica para América Latina y el Caribe [CEPAL], and Oficina Regional de Educación para América Latina y el Caribe de la Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura [OREALC/UNESCO], 2020).

The digital divide refers to the substantial inequality in access to new information and communication technologies (ICTs) (Ballestero, 2003, cited by Montenegro et al., 2020). This technological and digital gap is present in students and the teaching sector at different educational levels. In a study by Montenegro et al. (2020), this digital divide was analyzed from the perspective of teachers at the preschool, primary, and secondary levels of a Spanish community during the covid-19 pandemic. According to this research, the teachers perceived that the students did not achieve the minimum learning objectives during the confinement. This perception is due to the context linked to the Students' family environment, such as the availability of technological equipment and the economic situation. Similar research in rural Spain indicates a 30% digital divide among students during confinement (Álvarez-Álvarez and García Prieto, 2021).

On the other hand, the information and knowledge society promotes using digital devices that facilitate learning and achieve techno-pedagogical objectives (Pérez et al., 2018). That is, technology goes hand in hand with the development of the skills of twenty-first century students since it allows access to global knowledge (Arancibia et al., 2020). For Cabero-Almenara and Palacios-Rodríguez (2020), the ability to interpret and build messages using technology and various symbolic systems is a problem in this knowledge society. For this reason, ICTs have become central to educational processes that require developing skills and abilities that meet the new demands of the globalized world and are hyperconnected.

One of these competencies is digital competence, which relates to the confident, critical, and creative use of ICTs to achieve different goals (Wild and Schulze, 2020). It includes a series of skills in using ICTs, skills to search, process, and analyze information from various sources, learning to learn, capacity for abstraction, analysis, and synthesis, and ability to learn and update permanently (Fernández et al., 2019). The aim of the educational field is to integrate knowledge, pedagogy, and technology (Gisbert et al., 2016; Caena and Redecker, 2019).

Likewise, digital skills have to do with understanding the cultural context of the internet environment, the ability to communicate in online communities, the ability to create and distribute content, and skills to use digital technology for personal development (Kurnikova et al., 2021). Some authors propose a sociocultural model to develop teachers' digital competence based on four constructs: mastery, preference, reintegration, and appropriation of digital culture (Colás-Bravo et al., 2019). In any case, the use of technology in education for no reason should be separated from the context in which the educational process will take place since the different conditions in which education is given directly affect the success or failure of said process.

From the perspective of teacher development, the DTC presupposes a key competence for the digital world. Such competence is "holistic, situated, role-oriented in performance, function, and relationship, systemic, trainable, and constantly developing" (Castañeda et al., 2018, p. 14). The demand for digital competence is growing among teachers by linking various skills, knowledge, and attitudes of the digital environment. In this way, the promotion is made possible by effective learning strategies and innovative and inclusive interventions (Redecker and Punie, 2017). Teachers' digital familiarity and fluency contribute to an acceptable level of digital competence. In this sense, it raises their self-concept in digital competencies and the motivation to continue learning (Torres et al., 2022).

Several research studies have dealt with teachers' digital skills, even more so in the context of the pandemic, since

it caused this process to accelerate at different educational levels. Thus, Carrillo López and Hernández Gutiérrez (2022) analyzed the level of digital competence of 678 teachers from the Canary Islands of various educational levels and concluded that teachers at the Primary and Preschool levels have more ICT training than those in Secondary school. Likewise, teachers who work in private schools excel in the Auditory and Accessibility dimensions concerning those working in public schools; and teachers working in enclaves, who attend to special educational needs, are the ones with the best results in all dimensions.

Along the same lines, Fernández-Cruz and Fernández-Díaz (2016), when studying the ICT competencies of young teachers who belong to the so-called Generation Z and who teach at the primary and secondary levels in Spain, found that a good part of the participants in the study had a medium-low global assessment. These results indicate that even though this group of young people is generally attributed with a more significant command of technology, this does not go hand in hand with the training they have in applying ICTs in the educational field. Therefore, it is necessary to implement training programs to develop digital competencies in this young population of teachers (Grande-De-Prado et al., 2021).

In Latin America, research on digital competencies differs in findings and approaches. Thus, from a qualitative perspective, the level of digital competencies in higher education institutions is moderate, according to a study by Saltos et al. (2019). Similarly, Henríquez-Coronel et al. (2018) found diverse findings on Students' digital competencies, which leads them to affirm that young people do not possess high-level digital competencies. This affirmation leads to the assumption that teachers do not have them either.

There are also studies on the levels of digital competence in future teachers. Thus, Silva Quiroz et al. (2022) described the levels of teaching digital competence in 239 Chilean pedagogy students in seven universities. One of the results shows a significant difference in gender, where women scored higher than men in the indicator "Designs teaching-learning activities that consider the use of digital technology." This involvement in the female population suggests a more outstanding commitment to the acquisition of digital skills by women. For Sánchez and Rodríguez (2021), when evaluating the DTC, they found no significant differences. In this sense, the sex variable does not constitute a relevant variable. A similar result was obtained by Peral et al. (2015), stating that this variable does not allow to explain the level of digital competence accurately.

Another interesting aspect of digital competence is its relationship with other related competencies, such as media competence, since, after all, technology and media are inseparable. In their study, Gutiérrez-Martín et al. (2022) analyzed the perception of teachers about ICT competencies and media competencies and found a low level of this self-perception. Their findings also indicate that teachers give greater importance to media competencies than ICT competencies. For this reason, they propose a model called COMPROMETIC (teacher competencies in media and ICT) that integrates both types of competencies and suggests that they should not be viewed separately. This proposal is timely considering that it is through new media, such as social networks, that people of different ages interact and acquire new learning.

Despite differences in the competency domains, the achievements obtained show a greater advantage for young people. Their higher level of competence is due to their more significant contact with digital technologies (Mortis et al., 2013). The achievement generates relevant gaps in the DTC between teachers and students, older and younger. The younger ones are more accustomed to this type of resource (Fernández-Cruz and Fernández-Díaz, 2016).

In the Peruvian case, recent studies have been carried out on teaching digital skills in education, such as those by Rodríguez Martínez (2021) and Montalvo-Callirgos et al. (2022). The latter conducted a documentary review of teachers' digital competencies in the context of the COVID-19 pandemic. The results show that 98% of teachers have an elementary level in using ICTs, so it is necessary to undertake updating programs to use new technologies. It should not be forgotten that social and economic inequality has exacerbated the already existing digital divide in Peru, even more so in the context of the pandemic. In this context, significant differences are established in the DTC by gender, place of birth, and institution of study (Suárez-Guerrero et al., 2020).

Another study on DTC in Peru is by Vilchez Guizado and Ramón Ortiz (2022). They analyzed and evaluated the level of development of digital competencies of Secondary school teachers in the management of virtual mathematics teaching. They considered three categories of analysis: acceptance of digital technology, digital information management, and the generation of digital content, which had a positive and moderate correlation. These results allow us to conclude that the covid-19 pandemic has led to faster development of digital competencies in teachers, even to the point of feeling more empowered in using digital technologies.

Similarly, the pandemic has prompted studies on DTCs and their relationship with the Blended Learning modality in a Peruvian context. Thus, Apaza (2022) found a statistically significant relationship between DTCs and the B-learning modality. In Apaza's (2022) study, it is evident that the DTCs are essential to bringing about substantial educational changes. Thus, it positively influences the fulfillment of educational objectives, reflected in better academic performance. Hence the need for intensive training gradually develops levels from explorer (A1, A2) to expert (B1, B2) and then to a leader (C1,

C2), proposed by Cabero-Almenara and Palacios-Rodríguez (2020).

It should also be noted that for the Peruvian Ministry of Education (Ministerio de Educación del Perú [MINEDU], 2020), the promotion and development of the DTC is an absolute necessity. The Ministerio de Educación del Perú [MINEDU] (2020) National Survey of Teachers applied remotely shows that almost 70% have difficulties systematizing virtual educational experiences. Also, 35% of teachers express virtualization difficulties during teaching and individual and collective planning. The results place teachers within a traditional use of ICTs due to the limited achievements in digital literacy (Benavente et al., 2021).

Finally, it is worth mentioning that various researchers have measured digital competencies in different contexts, which has led to the developing of a series of instruments for this purpose. In Europe, the European Framework for Digital Competence of Teachers «DigCompEdu» was proposed in Redecker and Punie (2017) to support member states in promoting teachers' digital competence and innovative educational processes (Cabero-Almenara and Palacios-Rodríguez, 2020). Likewise, Cabero-Almenara et al. (2022) validated the DigCompEdu model of the European Union, which suggests that teaching digital competence depends on professional commitment, pedagogical skills, and the ability to develop Students' digital competence.

In previous work, Cabero-Almenara and Palacios-Rodríguez (2020) proposed six levels and competency progression of the European Framework for Digital Competence of Teachers "DigCompEdu." The proposed instrument is called "DigCompEdu Check-In," which aims to assess the strengths and needs of teachers' digital competencies. The proposed levels are Novice (A1); Explorer (A2); Integrator (B1); Expert (B2); Leader (C1); and Pioneer (C2), which served as the basis for the present research (Cabero-Almenara and Palacios-Rodríguez, 2020).

Based on the studies conducted on digital competence in different educational contexts, it is possible to see the challenges and unequal conditions teachers face in today's world's new technological scenarios. Therefore, there is a need to investigate this topic in the Peruvian area to obtain accurate and recent data on the digital competencies of Peruvian teachers of BE. In this sense, the present study proposes the following objectives:

- To evaluate the level of global digital competence of BE teachers from different Peruvian schools.

- To determine the level by area of digital competence of BE teachers from different Peruvian schools according to sex, employment status, age, and educational level.

Methodology

The sampling was non-probabilistic and purposive. The present study corresponds to a quantitative methodological approach with a non-experimental design. The research is descriptive, comparative, and cross-sectional (Hernández-Sampieri and Mendoza, 2018).

Sample

A total of 3,142 teachers participated in this study: 1,020 men (32%) and 2,122 women (68%). Participation was voluntary. The ages mainly ranged between 46 and 51 years (38%) and 36 and 45 years (33%). Regarding the professional characteristics of the sample, the teachers belong to the Basic Education (BE) of the public schools located in the province of Arequipa (Peru). The teachers surveyed are distributed at the levels of Preschool (18%), Primary school (32%), and, for the most part, teachers in Secondary school (50%).

Table 1 shows the distribution according to sex, age, the educational level at which they work, and employment status.

Instrument

The information collection instrument was the "DigCompEdu Check-in" questionnaire (Cabero-Almenara and Palacios-Rodríguez, 2020), based on the European Framework Teaching Competence and allows self-perception on the level of DTC.

The instrument includes the 22 questions that measure the six areas of Digital Competencies.

TABLE 1 Sociodemographic data of the sample.

	F	%
Sex		
Woman	2,122	67.5
Man	1,020	32.5
Age		
Under 25 years	29	0.9
Between 26 and 35 years	441	14.0
Between 36 and 45 years	1,047	33.3
Between 46 and 55 years	1,180	37.6
Between 56 and 65 years	442	14.1
Over 65 years	3	0.1
Labor educational level		
Preschool	555	17.7
Primary school	1,013	32.2
Secondary school	1,574	50.1
Employment status		
Hired	1,723	54.8
Appointed	1,419	45.2
Total	3,142	100.0

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TABLE 2 Structure of the "DigCompEdu Check-in" instrument.

Areas of digital competence	Competence	No. of items
Professional commitment	Organizational communication Professional collaboration Reflective practice Digital training	4
Digital resources	Selection Creation and modification Administration, exchange, and protection	3
Digital pedagogy	Teaching Guide Collaborative learning Self-directed learning	4
Evaluation and feedback	Evaluation strategies Analysis of evidence and tests Feedback and planning	3
Empowering students	Accessibility and inclusion Differentiation and personalization Student participation	3
Facilitating the digital competence of students	Information and media literacy Communication and digital collaboration Digital content creation Responsible use and wellbeing Digital problem solving	5

Next, Table 2 presents the organization of the instrument considering the six areas, the competencies, and the number of questions.

Regarding the scoring of the instrument, each question has five alternatives. Depending on the answer, it is scored as no commitment (0 points), partial knowledge (1 point), occasional use (2 points), increasing use (3 points), and systematic and comprehensive use (4 points).

Similarly, the instrument allows the overall grading of the teacher's digital competence, whose maximum score can be 88 and places in a digital competence level as described in Figure 1.

Procedure

The "DigCompEdu Check-in" questionnaire in Google Forms was used to assess teachers' digital competencies. The version includes necessary information on the research topic. The surveys were anonymous, and the participation was voluntary.

Data analysis

The data were analyzed using the IBM SPSS Statistics 25 program. Initially, normality tests were performed using the Kolmogorov-Smirnov test with a significance level $\alpha = 0.05$ with the *p*-value. Normality was not found in the sociodemographic variables: sex, labor educational level, and labor condition. Therefore, the non-parametric Mann-Whitney U and Kruskal-Wallis tests for independent samples were applied. Cohen's d was applied to measure the effect size of the differences by gender and labor condition: values of $d \geq 0.2$, $d \geq 0.5$, and $d \geq 0.8$ represent a small, medium, and large effect size, respectively. The age variable has normality, so the ANOVA parametric test was applied.

Results

The results obtained by teachers in the "DigCompEdu Check-in" questionnaire are presented in tables. The differences in the six competency areas of the questionnaire were analyzed

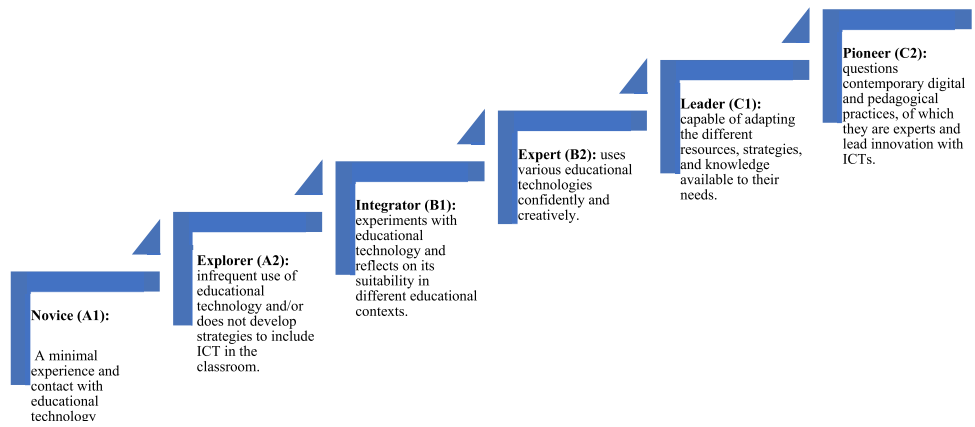

FIGURE 1
Levels of digital teaching competence.

TABLE 3 Results of Mann-Whitney U for the areas of digital teaching competence with effect size by sex.

Competency area	Sex	*n*	Ranges	U	*p*	Cohen's d
Professional commitment	Woman	2,122	1559.53	1056816.0	0.283	0.05
	Man	1,020	1596.41			
Digital resources	Woman	2,122	1528.10	990130.5	0.001	0.17
	Man	1,020	1661.78			
Digital pedagogy	Woman	2,122	1483.01	894445.5	0.001	0.3
	Man	1,020	1755.59			
Evaluation and feedback	Woman	2,122	1555.87	1049050.0	0.160	0.03
	Man	1,020	1604.02			
Empowering students	Woman	2,122	1551.70	1040210.0	0.076	0.09
	Man	1,020	1612.69			
Facilitating the digital competence of students	Woman	2,122	1465.89	1465.9	0.001	0.37
	Man	1,020	1791.21			

n, sample size; U, Mann-Whitney U; *p*, *p*-value; Cohen's d (effect size).

according to the sociodemographic variables: sex, employment status, age, and educational level.

Table 3 shows the comparison of the results according to sex. In three competency areas: professional engagement, assessment and feedback, and empowering students, no significant differences were found. Instead, there are differences in digital resources, digital pedagogy, and facilitating Students' digital competence. In the latter areas, male teachers score higher than female teachers, although the differences are slight. The competency areas are related to the sources and creation of digital resources, the implementation of the use of digital technologies, and the facilitation of Students' digital competence.

Table 4 shows a comparison of the results according to employment status. Significant differences were found in all competency areas. Hired teachers obtained higher scores than appointed teachers, although with a reduced effect, except in evaluation and feedback, where the result is significant. At this level, digital tools and strategies are related to evaluating and improving teaching-learning processes.

Regarding age, significant differences were found in the first two competency areas, professional commitment and digital resources (Table 5). Participants under 25 years and between 26 and 35 years obtained higher scores in these areas. The first area refers to professional interaction with colleagues, students, family, and other agents of the educational community. The second is related to the responsible use and administration of digital resources.

The differences in teaching digital competence according to labor educational level are shown in Table 6 secondary school teachers obtain higher scores than Primary and Preschool teachers. They are located after the Preschool teachers only in professional commitment.

Regarding the level of competence (see Figure 2), 42.7% of the participants are located at the Integrator level (B1). This level is characterized by reflection on the use of technologies in different educational contexts. 27.4% are at the Expert level (B2) in search of continuous improvement of their teaching practices. Finally, 18.5% is at the Explorer level (A2), an elementary domain. In this sense, external guidelines are required to improve the level of DTCs. No specific strategies have been developed to incorporate ICTs in the classroom (Cabero-Almenara and Palacios-Rodríguez, 2020). The low percentages in the most advanced and leadership levels in using ICTs, Leader (C1) and Pioneer (C2), motivate other teachers.

Discussion

The results referred to in the study differ from those found by Rodríguez Martínez (2021), for whom most teachers only have a basic level in the use of ICT (Apaza, 2022). The average levels of achievement corroborate that continuous and persevering participation in all types of training leads to a high level of involvement and motivation (Torres et al., 2022). The findings of Apaza (2022) evidence the importance of awareness and regularity of digital technologies in educational processes,

TABLE 4 Results of Mann-Whitney U for the areas of digital teaching competence with effect size according to employment status.

Competency area	Employment status	n	Ranges	U	*P*	Cohen's d
Professional commitment	Appointed	1,723	1505.27	1108348.5	<0.01	0.16
	Hired	1,419	1651.92			
Digital resources	Appointed	1,723	1495.07	1090782.0	<0.01	0.18
	Hired	1,419	1664.30			
Digital pedagogy	Appointed	1,723	1490.18	1082351.0	<0.01	0.19
	Hired	1,419	1670.24			
Evaluation and feedback	Appointed	1,723	1512.71	1121181.0	<0.01	1.57
	Hired	1,419	1642.88			
Empowering students	Appointed	1,723	1511.65	1119341.0	<0.01	0.14
	Hired	1,419	1644.18			
Facilitating the digital competence of students	Appointed	1,723	1506.20	1109958.5	<0.01	0.16
	Hired	1,419	1650.79			

n, sample size; U, Mann-Whitney U; *p*, *p*-value; Cohen's d (effect size).

which occurs similarly in the present study. Most teachers are at an integrative level (B1), characterized by a reflexive use of technologies. Another group of teachers, although in a smaller proportion, is at a higher level called experts (B2). Therefore, the levels of DTC achieved by the surveyed teachers are acceptable, coinciding with what Torres et al. (2022) referred to, highlighting professional commitment as a means of improvement.

TABLE 5 Results of the analysis of variance (ANOVA) for the areas of digital teaching competence according to age.

Competency area	Age	n	Mean	F	*p*
Professional commitment	Under 25 years	29	9.00	17.58	0.001
	Between 26 and 35 years	441	9.09		
	Between 36 and 45 years	1,047	8.66		
	Between 46 and 55 years	1,180	8.22		
	Between 56 and 65 years	442	7.49		
	Over 65	3	6.67		
Digital resources	Under 25 years	29	7.34	30.28	0.001
	Between 26 and 35 years	441	6.56		
	Between 36 and 45 years	1,047	6.01		
	Between 46 and 55 years	1,180	5.61		
	Between 56 and 65 years	442	5.15		
	Over 65	3	4.00		
Digital pedagogy	Under 25 years	29	8.07	1.39	0.226
	Between 26 and 35 years	441	8.31		
	Between 36 and 45 years	1,047	7.98		
	Between 46 and 55 years	1,180	7.89		
	Between 56 and 65 years	442	7.83		
	Over 65	3	6.00		
Evaluation and feedback	Under 25 years	29	6.76	1.85	0.099
	Between 26 and 35 years	441	6.86		
	Between 36 and 45 years	1,047	6.74		
	Between 46 and 55 years	1,180	6.70		
	Between 56 and 65 years	442	6.48		
	Over 65	3	4.67		
Empowering students	Under 25 years	29	6.45	2.14	0.057
	Between 26 and 35 years	441	6.73		
	Between 36 and 45 years	1,047	6.50		
	Between 46 and 55 years	1,180	6.43		
	Between 56 and 65 years	442	6.17		
	Over 65	3	4.67		
Facilitating the digital competence of students	Under 25 years	29	8.00	1.40	0.220
	Between 26 and 35 years	441	9.12		
	Between 36 and 45 years	1,047	9.02		
	Between 46 and 55 years	1,180	9.26		
	Between 56 and 65 years	442	9.02		
	Over 65	3	4.67		

Mean difference is significant at $p = 0.05$ by Duncan.

TABLE 6 Kruskal-Wallis H results for the areas of digital teaching competence according to labor educational level.

Competency area	Labor educational level	*n*	Ranges	Kruskal-Wallis H	*p*
Professional commitment	Preschool	555	1654.36	19.407	<0.01
	Primary school	1,013	1471.81		
	Secondary school	1,574	1606.44		
Digital resources	Preschool	555	1534.96	49.620	<0.01
	Primary school	1,013	1426.13		
	Secondary school	1,574	1677.94		
Digital pedagogy	Preschool	555	1151.11	196.739	<0.01
	Primary school	1,013	1503.84		
	Secondary school	1,574	1763.28		
Evaluation and feedback	Preschool	555	1538.73	8.033	<0.01
	Primary school	1,013	1519.69		
	Secondary school	1,574	1616.40		
Empowering students	Preschool	555	1377.31	53.724	<0.01
	Primary school	1,013	1508.35		
	Secondary school	1,574	1680.62		
Facilitating the digital competence of students	Preschool	555	939.80	369.451	<0.01
	Primary school	1,013	1565.15		
	Secondary school	1,574	1798.32		

n, sample size; *p*, *p*-value.

Considering the sex of the teachers who work in BE schools, discrepancies are found in three areas: digital resources, digital pedagogy, and facilitating Students' digital competence. In these areas, male teachers obtained higher scores than female teachers; but with little effect. In general, according to the scale (**Figure 1**), the average value obtained allows us to understand that most teachers are at the B1 integrator level (Rodríguez Martínez, 2021).

There are conflicting opinions on the incidence of the sex factor in the achievement of DTC. According to some researchers, there are significant differences (Silva Quiroz et al., 2022), and for others, they are not presented exhaustively (Peral et al., 2015; Sánchez and Rodríguez, 2021). The contradictions presented lay the foundations for future research, becoming the object of study. The expanded analysis of the sex variable will allow a better description of DTC and how to encourage their training.

By employment status, significant differences were found in all competency areas. Thus, hired (temporary) teachers obtained

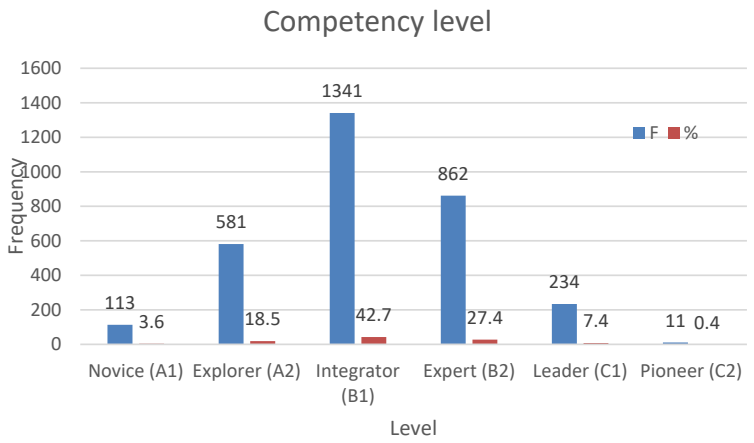

FIGURE 2
Levels of digital teaching competence of the participants. Score based on the global classification of teaching digital competence by Cabero-Almenara and Palacios-Rodríguez (2020).

higher scores than appointed (permanent) teachers, although the effect is little. Hired teachers are usually younger and are in a career initiation period, so their knowledge and willingness are more intense (Fernández-Cruz and Fernández-Díaz, 2016). The distinction by the domains achieved allows verification of the levels of the areas of competence, assessing what type of training will be the most appropriate for each teacher (Carrillo López and Hernández Gutiérrez, 2022). The differences between permanent and temporary teachers may be due to age. Younger hires have a better command of technological tools (Mortis et al., 2013). In addition, hired teachers show greater fluency and ease in "mobilizing" in the digital world (Torres et al., 2022).

Regarding age, the teachers surveyed showed significant differences in the first two areas of competence, professional commitment, and digital resources. Participants under 25 years and between 26 and 35 years obtained higher scores. The demand for digital competencies is essential in the current situation, where a large part of the educational process is associated with digital technology. Hence, the younger teaching population, under 35 years, has better domains (Fernández-Cruz and Fernández-Díaz, 2016). It should be noted that their proximity to digital technologies is closer, unlike those over 35 years. The manifest contrasts are not decisive since they combine other factors, such as digital divides (Suárez-Guerrero et al., 2020). The study shows that experience contributes to slightly higher results among teachers working with digital technologies for more years.

According to labor educational level, BE teachers in Secondary school obtain higher scores than Primary and Preschool teachers. Only in the professional commitment, they ranked after Preschool teachers. These educational level results differ from Carrillo López and Hernández Gutiérrez's (2022) findings. These researchers found that Primary and Preschool teachers had more ICT training than Secondary school teachers. The distinctions confirm that the educational level where teachers work is not a fully determinant for a higher or lower DTC. The results show that, on the one hand, the level achieved is closer to those predisposed to greater use, with an increasing and almost generalized tendency. On the other hand, there are demands from teachers for further updating (Grande-De-Prado et al., 2021).

Conclusion

The principal purpose of this research was to evaluate the level of digital competencies of BE teachers in different Peruvian schools. Regarding the competence level, most of the participants are at the Integrator level (B1), followed by the Expert level (B2) and the Explorer level (A2). The average levels achieved in the DTC show achievements in essential competencies that demonstrate their preparation in digital technologies. There are differences in the acquisition of the competency areas. Personal variables (age, sex), work, and educational level are related to the use of ICT since younger and hired teachers use more technological resources than appointed teachers who have been teaching for a longer time. Secondary-level teachers obtain better levels of digital competence than their peers in primary and preschool education. Likewise, male teachers reported higher levels of competencies than female teachers, which allows them to create digital resources and transfer them to students in the teaching-learning process.

In general terms, the study highlights that the differences in DTC contribute to the promotion of a reflexive praxis with a view to the continuous improvement of the educational process. Likewise, it contributes to adapting teaching practices to student needs (Vilchez Guizado and Ramón Ortiz, 2022). From that perspective, the DTC level responds to digital technologies

that promote inclusion, engagement, and mainly technological involvement fostering student autonomy (Kurnikova et al., 2021). In a broad sense, although the disparities are not profoundly significant, they provide a basis for further research. This way, the possible contrasts could be analyzed according to these and other sociodemographic variables (Sánchez and Rodríguez, 2021).

The study results make it possible to design training plans that respond to teachers' real and particular needs. The specific design would lead to higher levels of achievement. Advancing in this perspective is essential, given that certain demographic factors and the educational level where teachers work are not determining factors for a greater or lesser DTC. In this way, as they pass through distinctive and more demanding experiences, the competencies are affirmed. Such circumstances signify the need for a public policy recognizing teachers' innovation and good practices (Ministerio de Educación del Perú [MINEDU], 2020). In this regard, as Montalvo-Callirgos et al. (2022) point out, teacher updating plays a significant role. Universities should make a more outstanding commitment to training teachers in digital competencies. We must not forget the low percentages achieved at the Leader and Pioneer levels, which should significantly impact training. These levels represent the highest levels at the DTC level. Training this type of teacher should be a pending task for the coming years.

The use of ICT by teachers is fundamental in educational processes, so much so that current education cannot be understood without them. The DTC has become a key competence for the exercise of teaching. The pandemic has made it more visible, given the prominence of virtual and interactive scenarios. Circumstances demand changes and adaptations the surveyed teachers do not shun. Although they present distinctions in the levels of competence, in general, they are oriented toward progressive technological appropriations. In this perspective, sociodemographic factors are present considerably, making it evident that generational proximity to technological changes is significant. In essence, singularities to be considered are revealed and findings for future research. The application of a standardized questionnaire limits the study; although validated, not yet in the Peruvian context.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

AH-M: substantial contributions to the conception or design of the work and the acquisition of data, provide approval for publication of the content, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity. RN-P: drafting the work or revising it critically for important intellectual content, provide approval for publication of the content, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity. AB-P: substantial contributions of the interpretation of data for the work and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity. EG-C: substantial contributions to the conception or design of the work, drafting the work or revising it critically for important intellectual content in English, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity. OT-G: substantial contributions to the conception or design of the work and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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Enhancing cognitive combat readiness: Gamers' Behaviours concentrating on convergent learning style, tacit-latent, and kinetic-active knowledge acquisitions

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This study investigates gamers' learning styles and knowledge acquisition behavioural patterns. It argues that gamers usually have different characteristics transforming themselves to gain distinctive competencies. In other words, this study mitigates gamers' mechanistically distinctive attitudes and behaviours, enhancing their cognitive combat readiness, that they are on convergent learning style, tacit-latent, and kinetic-active knowledge acquisitions. Methodologically, it uses a field-experimental design using the "Clash Royale" game. Then, this research measures playing performances by average decks' score, card collection, battle deck combinations, and the usage of gold and gems. Moreover, it collects gamer respondents using a purposive sampling method by identifying them on social media and then challenging them to play. This research finds that gamers acquire new knowledge to enhance their capabilities with convergent learning styles and familiarity with the tacit-latent and kinetic-active knowledge types. Thus, it demonstrates its attitude and behavioural validities because their inner motives construct themselves always to win the game matches genuinely. Hence, it explains that gamers generally are brilliant young individuals whose impact is to create their tactically contemporary style due to the learning cycle ending in that convergent style. Likewise, these gamers simultaneously seek flexibility to enhance the game kinetically or elastically. The authors reveal that gamers' mental models show their learning styles and knowledge acquisition behaviours explained by their strong personalities, such as curious, workaholic, prestigious, and hedonic emotions.

KEYWORDS

learning style, knowledge acquisition, convergence, active, latent, kinetic, tacit

Introduction

This study investigates gamers' learning styles by comparing the convergent type to accommodative, divergent, and assimilative types. In addition, the authors simultaneously investigate gamers' knowledge acquisition focused on kinetic-active and tacit-latent models compared to actor-active and material-latent ones. Furthermore, the study connects gamers' learning styles and knowledge acquisition, constructing their specific behaviours (McCrow et al., 2014; Yousef, 2016; Hamdaoui et al., 2018). Developing this study's goal, the authors argue that gamers' personalities, like being curious, workaholics, and gaining prestige by dominating and winning matches, shape their cognition. Moreover, naturally dominant awareness, such as military troopers, affects their attitudes and behaviours in combat readiness (Yurechko, 1988; Griffith, 2002; Herspring, 2006). Meanwhile, this study proposes using cognitive combat readiness for gamer attitudes and behavioural characteristics. In brief, it argues that gamers emerge from all concepts or theories in their cognition, transforming to practical methods in finishing a match. On the other hand, gamers should always react and explore problem-solving efficiently with their cumulative knowledge. Thus, this study demonstrates that gamers' cognitive demands require them to be definite in their convergent learning styles and kinetic knowledge acquisition.

This study presents its novelties to answer the critical need of its investigation, arguing constructive contexts of gamers' attitudes and behavioural learning styles associated with their knowledge acquisition. Starting from the authors' explorative proposition, we captured that gamers' cognitive combat readiness is more likely equivalent to soldiers' combat readiness. However, we noted that gamers focus on their cognition only, and then we innovate the gamers' cognitive combat readiness. First, it argues that gamers' personality traits, such as military perspectives, are specific to combat readiness (Griffith, 2002; Strandenes et al., 2013; McCrow et al., 2014). It transforms this term into cognitive combat readiness for these gamers, meaning that gaming cognition is based on technical practises (Yurechko, 1988; Herspring, 2006; Tsarouhas and Makrygianni, 2017). Moreover, these gamers swiftly transform theories and concepts into technical practises implemented in problem-solving (Sánchez and Olivares, 2011; Sahasrabudhe and Kanungo, 2014; Dantas and Cunha, 2020). Thus, gamers internalise learning styles and knowledge acquisition, gaining distinctive attitudes and behaviours in convergent, kinetic-active, and tacit-latent contexts. Moreover, this study demonstrates that other people cannot adopt these gamers' learning styles and knowledge acquisition due to a lack of curiosity, a workaholic, and a sense of prestigious pressure. It also explains that cognitive combat readiness gamers gain highly coordinated communication and reduce asymmetric information amongst their partners.

This second novelty is this study's gamer-focused argumentation regarding convergent learning styles and concentrated on kinetic-knowledge acquisition. This research explains that gamers unconsciously adopt convergent learning styles due to no long durations when executing their decisions. In other words, gamers should condition their cognition on decisive punctuality (Manolis et al., 2013; Sahasrabudhe and Kanungo, 2014; García-Campos et al., 2020). With this loose timeliness in decision-making, the gamers will not win the matches. Then, they should emerge with their unique concepts and theories in technical and practical problem-solving. On the other side, this study explains that gamers face a multi-dimensional environment, affecting their proper response. The authors argue that gamers should consider three dimensions in thinking-feeling, judging-perceiving, and intuitive-sensing (Nacke et al., 2014; Dale and Green, 2017; Kamal and Radhakrishnan, 2019). The environment stimulates gamers to organise and adapt their cognition (Sadler-Smith and Riding, 1999; Goulding and Syed-Khuzzan, 2014; Seo et al., 2021) matches. This research explains that gamers consider multi-dimensional inputs processed in their comprehension to emerge a unique decision, formulating convergent learning styles. Furthermore, gamers' endowment concepts and theories, including previous experiential learning, made them flexible in switching their reactive, and newly explorative cognition (Dodd et al., 2005; Fox et al., 2018; Van der Lingen et al., 2020). When gamers do not have concepts, theories, and experiential values, they swiftly search for referential decision-making. Thus, they absorb in an elastically cognitive way, fashioned in tacit-latent, and kinetic-active knowledge acquisition.

Third, this research presents a novel argument in its methodology, elaborating on these gamers' attitudes and behaviours. Furthermore, it places gamers in convergent learning styles as the dominant one (Müller-Wienbergen et al., 2011; Hamdaoui et al., 2018; Hong et al., 2021) and simultaneously in kinetic-active and tacit-latent knowledge acquisitions (Linde, 2001; Zebal et al., 2019; Johannessen, 2021). Firstly, this research examines the cognitively dominant roles of gamers' convergent learning styles. Next, it investigates gamers' dominance in kinetic-active and tacit-latent knowledge acquisitions. Then, this research associates the gamers' learning styles and knowledge acquisition (Banner and Rayner, 2000; Strayer and Beitz, 2010; Hamdaoui et al., 2018); this relationship has the highest value compared to the others amongst those combining those styles and acquisitions. Secondly, this research examines the dominantly causal association higher than other combining ones. Finally, when the first and second stepped tests are valid, it shows the robustness of gamers' learning styles and knowledge acquisition and whether they have distinctive behaviours.

This study uses three clustered theories to explain the gamers' learning styles and knowledge acquisition. The first clustered theory pertains to accommodative, convergent, divergent, and assimilative learning styles (Papa et al., 2017; Hamdaoui et al., 2018; Hong et al., 2021). Moreover, this study focuses on gamers' divergent learning styles due to their personalities. The second cluster is knowledge acquisition explaining methodological choices of gamers' behaviours in enhancing their capabilities and competencies (Hung and Lin, 2015; Kamal and Radhakrishnan,

2019; Chung and Jung, 2020). In comprehending gamers' characteristics, this study argues that gamers probably engage in kinetic-active and tacit-latent learning because of their cognitive-behavioural suitability for the technological environment. Finally, the remaining cluster pertains to combat readiness viewed from the military approach (Yurechko, 1988; Rosen and Martin, 1998; Hanson, 2003; Erden et al., 2008). However, this study transforms this theory, embedding the cognitive combat readiness for gamers' attitudes and behaviours. As a result, it comprehends how gamers exhibit convergent learning styles, and kinetic-active and tacit-latent knowledge acquisitions due to the emergence of cognitive combat readiness. Moreover, it demonstrates that, cognitively, gamers should be combat-ready when they genuinely play a match to win.

This study contributes to the literature on practical and theoretical learning styles and knowledge acquisition, probably impacting academic performance. The first contribution is that combined convergent learning styles and kinetic-active knowledge acquisition present unique learning systems. It is also valid for the combined convergent learning styles and tacit-latent knowledge acquisition. Consequently, this study argues that learning systems assist students with convergent and kinetic-active or tacit-latent learning. Moreover, this combination will support academic and vocational learning emphasising practical jobs (Zebal et al., 2019; Jayalath and Esichaikul, 2020; Lei et al., 2021). Finally, this study comprehends that learning supremacy leads to this combination due to students' emerging reactive and explorative cognition (Jurado and Meza, 2017; Ewell et al., 2018; Khanmurzina et al., 2020). Hence, students can also enhance their competencies in decision-making when they face problematic situations and short-time pressures.

The second contribution relates to constructive behaviours for educator awareness to create students' cognitive combat readiness. Other perspectives are the enhancement of their cognitive combat readiness, making students always masculine and eager to accomplish their tasks (Johnson, 2010; Sanjamsai and Phukao, 2018; Khanmurzina et al., 2020). Then, educators have the responsibility to increase students' cognitive combat readiness. Moreover, they accentuate dimensions of combat readiness internalised to students' cognition, such as knowledge accumulation, practical transformation, problem-solving, etc. Conversely, this signals the need for resilient methods for students to engage their cognitive readiness and achieve a student-centred learning system (Strandenes et al., 2013; Tsarouhas and Makrygianni, 2017; Dantas and Cunha, 2020). Finally, this study demonstrates students' achievement of an efficient learning system due to their signified engagement. Hence, this cognitive combat readiness aligns with the conditionalism of student cognition in gaining competitive performances.

The remaining sections will discuss the theoretical framework to explain gamers learning styles and knowledge acquisition. The third section deals with research methods for learning style measurements and experimental games to acquire gamers' knowledge. Statistical results and findings are presented in section four. Finally, the study ends with conclusions and future research suggestions.

Literature review and hypotheses development

Learning styles

This study posits Keefe (1979) to explain that learning styles are individual cognitive and affective behaviours in interacting and reacting to environments. Griggs and Dunn (1984) differentiate between unique visual, auditory, and kinesthetic learning styles. Meanwhile, Allinson and Hayes (1996), Willingham et al. (2015) explain that learning styles based on individuals' preferences involve cognitive processes to differentiate between their intuitive and analytical thinking. Additionally, Abel et al. (2018), Alexander (2020), Olanipekun et al. (2020), Van der Lingen et al. (2020) categorise learning styles into; (1) accommodative; (2) convergent; (3) divergent; (4) assimilative. Most extant studies explain that accommodative learning styles acquire knowledge through deepened experiences from others. The individual with accommodative learning prefers to use intuitive techniques than critical logic. Convergent learning styles acquire knowledge using their endowed concepts and theories in their cognition. These convergent styles are also highlighted with their swifted transformation from concepts and theories to practical and technical methods. Divergent learning styles search knowledge visually, auditory and kinetically. The last is assimilative learning styles that acquire knowledge only through practising directly. Furthermore, this study considers to these extant research, concerning individuals' learning styles. However, those extant research did not relate these styles with gamers' cognitive behaviours, characterised by genuine combat readiness.

With four typological methods from previous research, this study argues that individuals search for the most suitable methods to achieve their performances. Then, it considers literature gaps in most extant research, specifically not discussing gamers' learning styles. Moreover, it investigates the relationship between the gamers' learning styles with specific behaviours and their effortful combat readiness. It explains that gamers receive knowledge, becoming a practical and technical tool to win a match. It infers that gamers simultaneously use visual, auditory and kinesthetic senses (Jurado and Meza, 2017; Hamdaoui et al., 2018; Hilvert-Bruce and Neill, 2020) to simulate all menus, features, elements and movements as if they are in the real world. On the other hand, this study uses extended learning styles and highlights that gamers lead to a convergent one (Manolis et al., 2013; Jurado and Meza, 2017; Hong et al., 2021) due to expertise in actualising concepts and theories transforming to be technical and practical.

This research identifies gamers' learning styles to capture their cognitive and affective behaviours. It posits Al Shaikh et al. (2019), García-Campos et al. (2020), and Kolb and Kolb (2005) to explain gamers' learning styles associating knowledge, capabilities and

attitudes. On the other hand, it posits Andreou et al. (2014), Dantas and Cunha (2020), and Garner (2000) argue that individuals' learning styles do not only restrict gaining answers but also identifying processes. Therefore, this research infers that learning style is a method for individuals to interact with others through their cognitions, affections, physics and environments (Li and Wang, 2013; Alexander, 2020; Olanipekun et al., 2020). Thus, it considers that gamers' learning styles focus on innovativeness to create and develop critical reasoning and problem-solving. Finally, the authors believe that gamers' learning styles will be convergent due to motives of expertise enhancement to win the match. In other words, gamers learn new concepts and theories that make them cognitively flexible. Therefore, gamers enhance their capabilities and competencies from constitutive dexterity skills, memory, mental strength, collective knowledge, and mechanical flows.

Knowledge acquisition

This study posits Cegarra-Navarro et al. (2019), Jayalath and Esichaikul (2020), and Olanipekun et al. (2020) to explain that individuals acquire knowledge through latent knowledge: tacit or material, or active: actor or kinetic, and cross-cutting catalyst epiphany (CCCE). Tacit-latent acquisition refers to acquiring knowledge through repetitive and directive practises. Material-latent acquisition acquires knowledge through media attributing with referential contents of structures, procedures, systems, etc. On the other hand, individuals who collect knowledge actively use their roles as actors, understanding through interfaces and rules. Thus, actor-active knowledge acquisitions refer to traditional teaching-studying methods. Kinetic-active explains that an individual pursues knowledge in reactive and explorative approaches through methodological flexibilities. The last is CCCE acquisition, in which individuals collect knowledge as it emerges unpredictably and immediately at random. The authors note that this CCCE is not involved in this study due to rare individual usage (Dufwenberg et al., 2010; Gneezy et al., 2010; Alexander, 2020). Therefore, considering all these extant research, this study infers that individuals acquire knowledge through two clustered acquisition types (Breen and Lindsay, 1999; McCrow et al., 2014; Alberti and Pizzurno, 2015; Visser-Wijnveen et al., 2016; Hamdaoui et al., 2018): latent or active. Hence, individuals search for knowledge through these possibilities aforementioned by these extant research, except for gamers with an unidentified acquisition. In addition, we believe that gamers acquire knowledge differently, fitting with their cognitive characteristics of combat eagerness. Thus, it arranges gamers' acquisition of knowledge that could be four possibilities: tacit-latent and actor-active; tacit-latent and kinetic-active; material-latent and actor-active; material-latent and kinetic-active.

This study argues that gamers' attitudes and behaviours are distinctive compared to others. Therefore, the authors believe that gamers have unique personalities in acquiring knowledge in tacit-latent (Howells, 1996; Erden et al., 2008; Lei et al., 2021) and kinetic-active types (Linde, 2001; Arthurs, 2007; Liew et al., 2021). The authors support this focused knowledge acquisition for gamers, a natural characteristic. Moreover, they pursue tacit-latent knowledge internalised into their cognition, indicating reflective behaviours (Hung and Lin, 2015; Seo et al., 2021; Thomas and Gupta, 2021). Comprehensively, gamers concentrating on kinetic-active knowledge acquisitions always enhance their expert skills to master their capabilities and competencies (Hung et al., 2015; Giampaoli et al., 2017; Jung J., 2020; Thongmak, 2020). Moreover, they improve their gamification mastery because of the need for repetitive requirements and dynamic flexibility for problem-solving. Finally, this study demonstrates gamers' strong personality traits of being curious, workaholic, prestigious, and hedonic to win the game, constructing themselves to focus on tacit-latent and kinetic-active knowledge acquisition.

Gamer behaviours and cognitively combat readiness

Gamers' behaviours are always associated with addictive enjoyment and hedonic personalities. This study also explains that people's stigma for being addicted to internet gamers and e-sport players does not exhibit a social distance from gamblers (Griffith, 2002; Johnson, 2010; Peter et al., 2019). The authors consider gamers' changing social behaviours and practises as an integral part of lifestyles in communication in their environments (Silva et al., 2015; Zimmermann et al., 2018; Bustamante et al., 2020; Khanmurzina et al., 2020). On the other hand, game types impact behavioural aspects due to conditional pressures, fatigue, endurance, etc. This study considers Chen et al. (2016), Drachen et al. (2014), Fox et al. (2018), Garcia-Manero et al. (2016) and clusters game types affecting gamers' behaviours, such as full game (highly frequent touches), hardcore game (acting as shooters and sports players), casual game (music, social aspects, and moderately thinking), and others (no preferences). Therefore, the authors infer that behavioural characteristics imply gamers' cognition because of frequent repetitions, intensive broadening of knowledge, proper communication without asymmetry, etc. For example, this study posits Ewell et al. (2018), Kamal and Radhakrishnan (2019), Li and Wang (2013), and Sanjamsai and Phukao (2018) to explain how gamers play for long durations to signify their imaginary thoughts, preparing multiple strategies for competitions.

This study posits Bustamante et al. (2020), Garcia-Manero et al. (2016), Jung C. W. (2020), Sumiyana et al. (2022), Teng (2008), who find that gamers' social communities affect their social awareness of always existing professionally. Furthermore, this study considers gamers' behaviours characterised by social aspects, such as communicating, collaborating, coordinating, competing, etc. It also highlights that gamers develop relational cohesiveness, building team loyalty (Sumino and Harada, 2004; Mandryk and Birk, 2017; Huang et al., 2021). This extant research

investigated the effectiveness of gamers' social communities, improving sound mentality or depressing it (Silva et al., 2015; Király and Demetrovics, 2017; Hilvert-Bruce and Neill, 2020; Rozgonjuk et al., 2021). Therefore, this study infers that game types and social communities construct gamers' behaviours, especially cyber aggressors and distractor characters.

Inferencing gamers as aggressors and distractors, this study associates gamers' learning styles and knowledge acquisition with combat readiness, such as military troopers. Combat readiness measures an army soldier preparing for combat (Rosen and Martin, 1998; Hanson, 2003; Tyler et al., 2012; Laanepere and Kasearu, 2021). Moreover, the authors highlight combat readiness equipped with mentality, weapons, technology, radio communication, etc. This study borrows the combat readiness measurement from the military, transforming it into gamers' behaviours. However, this measurement changed to cognitive combat readiness because gamers did not require physical fitness like soldiers. This study argues that gamers' cognitive combat readiness captures their learning styles and knowledge acquisition from various perspectives (Cegarra-Navarro et al., 2019; Alexander, 2020; Toth et al., 2020). It explains gamers' multi-dimensional conditions when they play a match against others. They should always utilise their conceptual and theoretical endowments to win the matches (Nacke et al., 2014; Dale and Green, 2017; Sumiyana et al., 2022).

On the other hand, this study supports the constructive measurement of cognitive combat readiness because gamers situate themselves in curiosity, excitement, anxiety, etc. Moreover, gamers should control their cognition to be innovative to win the game match. Gamers use innovativeness to actualise their cumulative concepts swiftly, theories and experiential values to challenge and attack their enemies in the gams (Hartman et al., 2006; Ladeira et al., 2016; Thongmak, 2020). In other words, gamers always search for the subsequent knowledge needed to master their cognitive combat readiness and win competitions (Yurechko, 1988; McAllister et al., 2013; Alexander, 2020). Furthermore, the study summarises that gamers' behaviours require them to accumulate knowledge, enhance innovativeness and solicit mastery. Finally, gamers should align their learning styles and knowledge acquisitions to control their talent to succeed in winning matches.

Hypotheses development

This study argues that gamers' convergent learning styles generally use concepts, theories and experiential learning values to be more adaptive and innovative due to game competitions. Elements are abstract conceptualisation and active experimentation, and gamers can accumulate theoretical and practical knowledge, actualising the match (Manolis et al., 2013; Goulding and Syed-Khuzzan, 2014; Hamdaoui et al., 2018). Moreover, gamers having both elements could enhance their cognitive combat readiness due to fundamentally acquiring that knowledge to be practised in the matches to win the competition (Herspring, 2006; Tyler et al., 2012; Khenissi et al., 2016). On the other hand, gamers facing various challenges in every match must be innovative to win the competition (Ladeira et al., 2016; Alexander, 2020; Thongmak, 2020). Furthermore, the authors demonstrate that these elements of abstract conceptualisation and active experimentation direct gamers' convergent learning styles to mastering their cognitive combat readiness. Thus, gamers are always charged with personal innovativeness to win the match over other gamers. In other words, they cope with avoiding match losses with their learning styles convergently. Then, they can shorten the time needed to rotate their experiential learning values compared to other techniques. Therefore, this study formulates hypothesis H1 below.

> *H1*: Gamers' convergent learning styles gaining their cognitive combat readiness are higher than others.

Naturally, gamers always accumulate tacit-latent knowledge aligning with their long-run capacities and demands. When gamers have gained tacit-latent knowledge, they can actualise their expertise, skill and competencies to win each game match. The same applies to kinetic-active knowledge acquisition (Gray, 2001; Kamal and Radhakrishnan, 2019; Wang et al., 2020; Lei et al., 2021). In other words, gamers' tacit-latent knowledge enhances their cognitive combat readiness (Griffith, 2006; Herspring, 2006; Tsarouhas and Makrygianni, 2017). Moreover, gamers always face various situations ending with the requirement to conduct problem-solving swiftly and innovatively. This study explains that gamers' tacit-latent knowledge could expose their reflective skills to higher combat readiness than material-latent ones (Park and Moon, 2003; Dodd et al., 2005; Strandenes et al., 2013; Toth et al., 2020; Seo et al., 2021). On the other hand, gamers' kinetic-active knowledge can adapt to challenging competitions. Moreover, gamers with highly accumulated tacit-latent and kinetic-active knowledge acquisitions can easily comprehend their cognitive combat readiness in each match because of enhanced adaptive behaviours (Griffith, 2006; Goulding and Syed-Khuzzan, 2014; Jayalath and Esichaikul, 2020). Therefore, this study explains that gamers orienting on the accumulated tacit-latent and kinetic-active knowledge acquisitions gain their cognitive combat readiness compared to the material and actor-active ones. In addition, the authors argue that these knowledge acquisitions are the most efficient approaches for gamers because of constructing their cognitive flexibilities. Moreover, these acquisitions structuralise gamers achieving more adaptive cognition facing dynamic situations with skill and expertise endowments. Thus, it constructs hypotheses H2 and H3 below.

> *H2*: Gamers' tacit-latent knowledge acquisitions gaining their cognitive combat readiness are higher than material-latent ones.

H3: Gamers' kinetic-active knowledge acquisitions gaining their cognitive combat readiness are higher than actor-active ones.

This study proposes that formal learning styles and knowledge acquisition will quickly lead to mastery of capabilities and competencies. Therefore, gamers' convergent learning styles develop their endowed concepts, theories and experiential values to repetitively practise in the next game in a competition (Jurado and Meza, 2017; Papa et al., 2017; Hong et al., 2021). Simultaneously, gamers with convergent styles train themselves to improve their combat readiness Johnson (2010), Rosen and Martin (1998), Tsarouhas and Makrygianni (2017) through heavy preparation and calculation of dynamic situations to stabilise the match-winning in the game. Gamers are naturally interested in technical and methodological practises, mastering their cumulative knowledge implemented in subsequent competitions. Furthermore, this study acknowledges that gamers' convergent learning styles continue to acquire tacit-latent knowledge (Howells, 1996; Zebal et al., 2019; Lei et al., 2021) and kinetic-active ones (Griffith, 2002; Hamdaoui et al., 2018; Jayalath and Esichaikul, 2020). For example, they would no longer look at the keyboard to run the game competition. Then, gamers' knowledge acquisition enhances their cognitive combat readiness, practising in the tournaments. In brief, this study explains that compounds of convergent learning styles and tacit-latent or kinetic-active knowledge acquisitions could lift gamers' expertise skills and competencies. Moreover, the authors argue that gamers always enhance their situational competition fits, inducing multi-features, multi-tools, and timeliness execution into their cognition. Finally, gamers always search for exceptional skills and expertise that can be delayed any longer. Therefore, it formulates hypotheses H4 and H5 below.

H4: Gamers' convergent learning styles and tacit knowledge acquisitions gaining their cognitive combat readiness are higher than other and material-latent ones.

H5: Gamers' convergent learning styles and kinetic-active knowledge acquisitions gaining their cognitive combat readiness are higher than other styles and actor-active ones.

Research method

Research design and respondent collections

This research design uses respondents who are gamers categorised into each learning style. In addition, they are also either engaged in active knowledge acquisitions, such as active (actor or kinetic) or latent ones (tacit or material). In other words, a respondent has a single learning style and an active knowledge acquisition of actor or kinetic, or a latent one that is tacit or material. Furthermore, this study collects respondents for each cell numbering about 30 gamers. Thus, it manages all the respondents, who number about 240 gamers, because they have acquired active and latent types of knowledge. On the other hand, this study has a field-experimental research design with the matrices of 4×2 for learning styles and active knowledge acquisitions and 4×2 for latent ones. In addition, this research uses two sequential data collections in the field experiment. The first sequence is that the authors identify gamers by social media. Furthermore, the second one is that we ascertain these gamers with the year of experience. Moreover, we challenge these gamers to match with us with Clash Royale (Table 1).

This research collects the data using random purposive sampling. It frames collected homogeneous respondents with these criteria: (1) having played games for more than a year; (2) having competed in at least one tournament; and (3) playing for more than 3 h daily. The criteria intend to minimise confounding bias, used to keep causality. This study identifies gamers on social media, and the researchers challenge them to play this experimental game. In addition, questionnaires are sent to these gamers to fill in. Furthermore, this study uses these questionnaires to measure gamers' learning styles and knowledge acquisition. Finally, the research treats gamers with specific manipulated measurements for their cognitive combat readiness developed and conducted by the researchers. Additionally, the authors challenge the participants to be reactive, innovative, aggressive, and explorative in these matches. In addition, the researchers score gamers' cognitive combat readiness using an ideal score depending on the game's itemising.

Variable measurements and recorded manipulation

This study used extant research on learning styles, knowledge acquisition and combat readiness. The researchers first sent a questionnaire to measure gamers' learning styles and knowledge acquisition in the data collection process presented in Appendix A. Moreover, in this data collection process, the researchers manually record an ideal deck's average score achieved by the gamers to measure their cognitive combat readiness. This study uses the specified "Clash Royale" game in this context. Thus,

TABLE 1 Research design.

		Knowledge acquisitions			
		Active		Latent	
		Actor	Kinetic	Tacit	Material
Learning Styles	Accommodative	Cell-A	Cell-E	Cell-1	Cell-5
	Convergent	Cell-B	Cell-F	Cell-2	Cell-6
	Divergent	Cell-C	Cell-G	Cell-3	Cell-7
	Assimilative	Cell-D	Cell-H	Cell-4	Cell-8

the authors chose this game for its relevancy to gamers' confidence in the complex featured measures, the many options to implement strategies, game-match readiness in the short duration, personal innovativeness, and multiple flows of cognitive states. Moreover, this study fits this game type by using various decks to measure cognitive combat readiness. This recording is the manipulative treatments conducted by researchers. This average score form that measures gamers' mental combat readiness is in Appendix B.

Statistical tests

This study examines all hypotheses by comparing cells according to the hypothetical contents. It uses mean comparison tests of ANOVA independent sample *t*-test. For example, testing hypothesis H1 identifies gamers' convergent learning styles gaining a cognitive combat readiness higher than other learning styles. It compares the Cell-B and F higher than other cells in active knowledge acquisitions. In latent knowledge acquisitions, it reaches Cell-2 and Cell-6 higher than other cells. This study presents these closed-comparative equations in Models (1)-(5) for shortage statements of all hypotheses. Finally, it supports the ease of readability for these hypotheses tests by presenting comparative equations below. Meanwhile, this study uses the ANOVA independent *t*-test, and when it fails to diagnose these comparisons, it transforms into a statistical comparative-contrast analysis.

$$\mathbf{H1}: \text{Cell}-\text{B};\text{F} > \text{Cell}-\text{A};\text{E};\text{C};\text{G};\text{D}\ \&\ \text{H}, \text{and}\ \text{Cell}-2;6 > \text{Cell}-1;5;3;7;4\ \&\ 8 \quad (1)$$

$$\mathbf{H2}: \text{Cell}-1;2;3;\&4 > \text{Cell}-5;6;7\ \&\ 8 \quad (2)$$

$$\mathbf{H3}: \text{Cell}-\text{E};\text{F};\text{G};\&\text{H} > \text{Cell}-\text{A};\text{B};\text{C};\&\text{D} \quad (3)$$

$$\mathbf{H4}: \text{Cell}-2 > \text{Cell}-5;\text{Cell}-2 > \text{Cell}-7;\ \text{Cell}-2 > \text{Cell}-8;\text{Cell}-2 > \text{Cell}-5;7;\&8 \quad (4)$$

$$\mathbf{H5}: \text{Cell}-\text{F} > \text{Cell}-\text{A};\text{Cell}-\text{F} > \text{Cell}-\text{C};\ \text{Cell}-\text{F} > \text{Cell}-\text{D};\text{Cell}-\text{F} > \text{Cell}-\text{A};\text{C};\&\text{D} \quad (5)$$

Statistical results

This study collects participants in two steps. The first step identifies gamers through social media, marking them as real players. Then, the authors ask these identified gamers to answer a questionnaire using Google Forms. In the second step, the authors challenge these participants to a match in "Clash Royale" with others or the authors in an appointed public area. Moreover, this research took 7 months to collect data samples, resulting in 132 gamers. It also deleted nine participants who did not complete the gaming stages, meaning there were 123 in the final sample. Then, overall data show that 79 participants are male (64.22%), with game expertise, 78 have more than 1 year of experience (63.41%), and 90 have been involved in at least one tournament (73.17%). Thus, this study infers that the data collected are from experienced gamers presented in Table 2.

Table 3 presents the number of participants, mean, and standard deviation of respondents' cognitive combat readiness occupying each cell. This research formerly conducted a pilot test to validate the questionary. After collecting the first eight participants, we believed no material doubts, and then we continued to collect the following participants. Furthermore, participants with accommodative-actor have the lowest mean value of 3.139. Conversely, the highest mean value of 4.586 is participants concentrating on the convergent-kinetic. Furthermore, the authors infer that each data item typically deviates from the mean values, reflecting central homogeneity. Thus, this study concludes that each data cell is typically distributed, which could be compared parametrically.

This study has designed validity and reliability tests for the 123 respondents. Table 4 shows the test results for each cell. First, Panel-A shows that the factor loading value of each item is more than 0.5, gaining convergent validity. In addition, the Corrected-Item-Total Correlation value for each item question is more than 0.5 and never higher than these factor loading values, indicating the discriminant validity. Then, Cronbach's alpha value shows that each item value is more than 0.8 and is not higher than the compounded value. Thus, this study infers that each variable achieves high reliability. In addition, the study develops specific measurements for material knowledge acquisition employing scoring systems equivalent to a 5-points Likert scale. Specifically, Panel-B shows that the 10-item questions are material-latent types. Each correct answer is valued at 0.50, and 0.00 for the wrong answer, reaching a maximum score of 5.00. Therefore, the authors conclude that each item score gained a fixed point.

TABLE 2 Demographic data.

Learning styles	Frequency						
	n	Gender		Gamer's experiences		Tournament	
		Male	Female	<1-year	>1-year	Yes	No
Accommodative	31	21	10	14	17	20	11
Convergent	37	25	12	5	32	34	3
Divergent	25	17	8	11	14	17	8
Assimilative	30	16	14	15	15	19	11
Total	123	79	44	45	78	90	33

TABLE 3 Descriptive statistics.

x: cognitively combat readiness		Knowledge acquisitions			
		Active		Latent	
		n: 246		246	
		$\bar{x}$: 3.857		3.928	
		SD: 0.8673		0.9070	
		Actor	**Kinetic**	**Tacit**	**Material**
		123	123	123	123
		3.628	4.087	4.111	3.744
		0.9635	0.6901	0.7922	0.9780
Learning	**Accommodative**				
Styles	*n*: 124;	31	31	31	31
	$\bar{x}$: 3.841;	3.139	4.054	3.849	3.613
	SD: 0.9089	0.8147	0.5715	1.0322	0.9102
	Convergent				
	148	37	37	37	37
	4.462	4.488	4.586	4.477	4,297
	0.5296	0.4695	0.5048	0.5960	0.5199
	Divergent				
	100	25	25	25	25
	3.563	3.460	3.887	3.907	3.000
	0.9701	0.9660	0.6955	0.6420	1.2162
	Assimilative				
	120	30	30	30	30
	3.700	3.213	3.806	3.967	3.817
	0.8268	0.8776	0.7156	0.6800	0.8457

Table 5 is the continued process of comparing the mean values of the collected data from participants in Table 3. Then, we compare amongst cells resulting mean differences, *t*-values and significances with asterisk signs. Furthermore, Table 5 exhibits the statistical results for all mean comparison hypotheses, revealing the overall supported views in Models (1)–(5). Specifically, hypothesis H1 proposed that active and latent knowledge acquisition mastered by convergent gamers' learning styles have the highest combat readiness compared to others. The statistical results support hypothesis H1 with a mean difference of 0.7991 and a *t*-value of 7.449, which is a significant 1.00%. Likewise, hypothesis H2 is supported, meaning that gamers' combat readiness dominated the knowledge acquisition of tacit-latent and kinetic-active learning compared to others, with a mean difference of 0.3672 and a *t*-value of 3.924. This hypothesis was statistically significant at 1.00%. Finally, supporting hypothesis H3, statistical results at a significance level of 1.00% confirmed that kinetic-active gamers have higher combat readiness than kinetic-actor with a 0.4587 mean different value and 7.356 *t*-value.

The statistical results show a mean value of 4.477 and a standard deviation of 0.596 from the testing of hypothesis H4. Overall, the mean difference, *t*-value and significance were 0.4587, 7.356, and 1.00%, respectively. Therefore, this statistical result supports hypothesis H4, arguing that convergent-tacit gamers demonstrate the highest combat readiness compared to those material-others.

TABLE 4 Validity and reliability.

Panel-A

Variables	Item	Factor loading	Corrected-item-total correlation	Cronbach's alpha	
Accommodative					
Actor	Act1	0.801	0.760	0.928	0.934
	Act2	0.627	0.599	0.933	
	Act3	0.822	0.768	0.928	
	Act4	0.632	0.587	0.932	
	Act5	0.906	0.875	0.924	
	Act6	0.580	0.436	0.935	
	Act7	0.838	0.814	0.926	
	Act8	0.679	0.623	0.933	
	Act9	0.757	0.730	0.929	
	Act10	0.680	0.650	0.931	
	Act11	0.667	0.599	0.932	
	Act12	0.782	0.715	0.929	
	Act13	0.615	0.559	0.933	
	Act14	0.863	0.829	0.926	
	Act15	0.657	0.636	0.932	
	Act16	0.566	0.487	0.934	
Kinetic	Kin1	0.943	0.926	0.958	0.964
	Kin2	0.788	0.754	0.963	
	Kin3	0.836	0.799	0.962	
	Kin4	0.880	0.847	0.960	
	Kin5	0.826	0.791	0.962	
	Kin6	0.850	0.813	0.961	
	Kin7	0.958	0.945	0.958	
	Kin8	0.806	0.769	0.963	
	Kin9	0.903	0.880	0.960	
	Kin10	0.873	0.850	0.960	
	Kin11	0.783	0.739	0.964	
	Kin12	0.764	0.730	0.963	
Convergent					
Actor	Act1	0.897	0.875	0.966	0.969
	Act2	0.884	0.861	0.967	
	Act3	0.910	0.893	0.966	
	Act4	0.883	0.856	0.967	
	Act5	0.896	0.877	0.966	
	Act6	0.913	0.891	0.966	
	Act7	0.894	0.882	0.966	
	Act8	0.861	0.835	0.967	
	Act9	0.766	0.733	0.969	
	Act10	0.781	0.752	0.968	
	Act11	0.850	0.824	0.967	
	Act12	0.876	0.849	0.967	
	Act13	0.763	0.730	0.969	
	Act14	0.902	0.879	0.966	
	Act15	0.886	0.869	0.966	
	Act16	0.478	0.444	0.975	

(Continued)

TABLE 4 (Continued)

Panel-A

Variables	Item	Factor loading	Corrected-item-total correlation	Cronbach's alpha	
Kinetic	Kin1	0.763	0.698	0.913	0.920
	Kin2	0.764	0.715	0.912	
	Kin3	0.821	0.773	0.910	
	Kin4	0.800	0.747	0.911	
	Kin5	0.766	0.707	0.912	
	Kin6	0.571	0.507	0.922	
	Kin7	0.539	0.467	0.924	
	Kin8	0.816	0.768	0.909	
	Kin9	0.790	0.732	0.911	
	Kin10	0.545	0.480	0.922	
	Kin11	0.881	0.830	0.906	
	Kin12	0.808	0.747	0.911	
Divergent					
Tacit	Tac1	0.832	0.655	0.896	0.856
	Tac2	0.932	0.816	0.727	
	Tac3	0.904	0.752	0.783	
Assimilative					
Tacit	Tac1	0.897	0.766	0.882	0.898
	Tac2	0.880	0.741	0.905	
	Tac3	0.959	0.895	0.769	
Panel-B					
	n	**Item**	**Scoring**	**Total**	
Material-divergent and assimilative	55	10	0.5	5	

Furthermore, hypothesis H5 in convergent-kinetic learning shows a mean value of 4.622 and a standard deviation of 0.285. This mean difference value is 1.3276, and the *t*-value of 8.558 with a 1.00% significance level, demonstrating that convergent-kinetic is higher than those actor-others. In the participants' field experiment, this study presents statistically robust results. It powerfully demonstrates that convergent-kinetic gamers have the highest combat readiness amongst those actor-others in mastering their knowledge acquisition. Thus, hypothesis H5 is supported twice.

Discussion and findings

This research investigates gamer behaviours in acquiring knowledge through convergent and tacit-latent or kinetic-active learning styles. It demonstrates the specified gamer behaviours in this style and acquisition measuring using cognitive combat readiness. This study's statistical tests show high validity that gamers improve their knowledge through convergent techniques. Moreover, this research recognises that gamer behaviours are laid on the convergent type because they are people with excellent intellectualism. Therefore, it highlights the gamer's reliance on personal innovativeness completed by cognitively dynamic flexibilities (Griggs and Dunn, 1984; Jurado and Meza, 2017; Hamdaoui et al., 2018). Thus, it explains that gamers always simulate all the menus, features, elements and movements they face in the real world. Gamers actualise their gamification expertise based on cumulative concepts and theories (Manolis et al., 2013; Ladeira et al., 2016; Jurado and Meza, 2017). As a result, gamers always internalise technical and practical approaches to executing highly complex decision-making. On the other hand, this study argues that gamers confront the situation of narrowed periods and uninterrupted rests (Alexander, 2020; Olanipekun et al., 2020; Huang et al., 2021), resulting in dexterous memory and mental strength. Finally, the authors find no other choices for these gamers to choose learning styles of the convergent type.

This study finds that gamers acquire incremental knowledge with tacit-latent and kinetic-active learning. Furthermore, it explains that gamers should use these knowledge acquisitions to complete their loaded cognitions. This research also demonstrates that gamers comprehend their expertise through tacit-latent learning due to the need to engage in reflective practise (Howells, 1996; Erden et al., 2008; Wang et al., 2020). Furthermore, it demonstrates that gamers should permanently eliminate their curiosities, mental inferiorities and attitudinal anxieties. On the other hand, gamers could probably be engaged in kinetic-active knowledge acquisitions because they must update their high-skill capabilities (Strayer and Beitz, 2010; Jung J., 2020; Thongmak, 2020). Thus, the authors demonstrate that gamers always upgrade their capability to master gamification (Zebal et al., 2019; Chung and Jung, 2020; Thomas and Gupta, 2021) to win competitions. On the other hand, a gamer should arrange various procedures to practise them efficiently. Moreover, the gamer should direct procedurally decisive flows into a shortened mechanism due to the need for punctual decision-making (Linde, 2001; Arthurs, 2007; Liew et al., 2021). Finally, this study demonstrates that gamer behaviours improve their knowledge with conditionally elastic-active acquisitions. Hence, gamers maintain their kinetic-active ability to protect inferiority and maintain prestigious intellectuality.

The authors explicitly provide robust conclusive evidence that gamers' learning styles and knowledge acquisition end in measuring their cognitive combat readiness. We demonstrated that those approaches are superior to gamer behaviours with convergent types comprehended by tacit-latent and kinetic-active learning styles (Rosen and Martin, 1998; Tyler et al., 2012; Laanepere and Kasearu, 2021). Furthermore, this study infers that gamers shape their cognition to be innovative to challenge and attack their enemies in games (Hartman et al., 2006; Ladeira et al., 2016; Thongmak, 2020), such as army troopers. In addition, gamers' behavioural characteristics consistently improve their cognitive combat readiness because of future complex challenges. Moreover, gaining knowledge through tacit-latent and kinetic-active constructs of gamers' strong mentality (Silva et al., 2015;

TABLE 5 Hypothesis results.

Hyp.	Mean (SD)	Cells	Mean (SD)	Cells	Mean diff. (*t*-value)
H1	4.537 (0.487)	Active-Convergent	3.139 (0.8147)	Accommodative	1.3978 (10.872)***
			4.054 (0.5715)	Divergent	0.4831 (4.404)***
			3.460 (0.9660)	Assimilative	1.0769 (7.278)***
			3.588 (0.8452)	All above	0.7991 (7.449)***
	4.387 (0.563)	Latent-Convergent	3.849 (1.0322)	Accommodative	0.5379 (3.438)**
			3.613 (0.9102)	Divergent	0.7745 (5.304)***
			3.907 (0.6420)	Assimilative	0.4807 (3.562)**
			3.706 (0.9464)	All above	0.6810 (5.763)***
H2	4.111 (0.792)	Tacit	3.744 (0.9780)	Material	0.3672 (3.924)***
H3	4.087 (0.690)	Kinetic	3.628 (0.9635)	Actor	0.4587 (7.356)***
H4	4.477 (0.596)	Convergent-Tacit	3.613 (0.9102)	Accommodative-Material	0.8646 (4.702)***
			3.000 (1.2162)	Divergent-Material	1.4775 (6.361)***
			3.817 (0.8457)	Assimilative-Material	0.6608 (3.745)***
			3.506 (1.0333)	All above	0.9717 (5.343)**
H5	4.586 (0.505)	Convergent-Kinetic	3.139 (0.8147)	Accommodative-Actor	1.4465 (8.949)***
			3.460 (0.9660)	Divergent-Actor	1.1256 (5.994)***
			3.213 (0.8776)	Assimilative-Actor	1.3731 (8.027)***
			3.258 (0.8823)	All above	1.3276 (8.558)***
Robustness: Field-experiment score					
H5	4.622 (0.285)	Convergent-Kinetic	4.430 (0.2748)	Accommodative-Actor	0.1915 (2.805)*
			4.280 (0.4780)	Divergent-Actor	0.3416 (3.525)**
			4.389 (0.2914)	Assimilative-Actor	0.2327 (3.290)**
			4.372 (0.3521)	All above	0.2495 (3.805)***

Király and Demetrovics, 2017; Rozgonjuk et al., 2021) uses the attitudinal and behavioural improvements as aggressors. This elastic-active knowledge acquisition also supports the gamers' cognitive combat readiness in building team loyalty (Hanson, 2003; Sumino and Harada, 2004; Mandryk and Birk, 2017). Moreover, the authors explain that gamers use cognitive combat readiness to win the pressured matches, execute punctual decisions (Tyler et al., 2012; Tsarouhas and Makrygianni, 2017; Laanepere and Kasearu, 2021) and compete in a chaotically pressured environment (McAllister et al., 2013; Alexander, 2020; Sumiyana et al., 2022). Finally, this study suggests that gamers have an alternative option to learn convergently and acquire knowledge with a tacit-latent and elastic-active style due to achieving superiority in cognitive combat readiness and reaching strong-mental combat readiness.

This study has implications for vocational learning systems and procedures concentrating on appropriate learning styles and knowledge acquisition. As with gamer behaviours, vocational students should train and educate themselves to achieve high cognitive work readiness (Strandenes et al., 2013; Zebal et al., 2019; Lei et al., 2021). This study demonstrates that achieving mental work readiness frames different learning systems and procedures: convergent learning styles and knowledge acquisitions with tacit-latent or kinetic-active styles. Furthermore, this study explains that vocational students get their capabilities and competencies according to an industry's needs. In other words, academic and vocational learning must arrange its learning system to create human resources ready to practise work (Barlett et al., 2009; Manolis et al., 2013; Hamdaoui et al., 2018) supported by student-centred learning systems. Thus, academic and vocational learning or training institutions treat students according to convergent learning styles. Likewise, this study argues for the need to treat vocational students with learning methods and a curriculum to lead them to focus on tacit-latent and kinetic-active learning. Finally, this study believes that curriculum designs in learning methods and knowledge mastery, like the behaviour of these gamers, have the lowest production cost in creating cognitive work readiness.

This study emphasises the supremacy of cognitive combat readiness as the final embodiment of learning styles and knowledge acquisition. Therefore, conceptually, it demonstrates the crucial uses of cognitive work readiness for academic and vocational learning and skills training systems. The superiority of this cognitive work readiness refers to the inference of mental combat readiness with the specification of beliefs, attitudes, and behaviours that concentrate on reactive and explorative abilities (Herspring, 2006; Strandenes et al., 2013; Tsarouhas and Makrygianni, 2017). Furthermore, this study demonstrates the power of young human resources with a signified engagement that, environmentally speaking, aligns with the conditionalism of student cognition in achieving competitive performances (Chen et al., 2016; Bustamante et al., 2020; Dantas and Cunha, 2020). Thus, the high-cognitive readiness of students would gain incremental capabilities and competencies (Tsarouhas and

Makrygianni, 2017; Sanjamsai and Phukao, 2018; Khanmurzina et al., 2020). On the other hand, they can work with a high level of team loyalty and a strong mentality in the face of complex challenges, pressured matches, and chaotic environments. The authors demonstrate that vocational students and trainees should be permanently within a state of cognitive work readiness when they enter the workforce to be genuinely competent.

Conclusion, limitation, and future research

This study concludes that gamers exhibit convergent learning styles and acquire knowledge by tacit-latent and kinetic-active. Furthermore, it measures gamers' cognitive combat readiness, learning styles and knowledge acquisition consequences. Moreover, this study suggests that with high intellectuality markers, gamer behaviour focuses on learning style models and knowledge acquisition to improve capabilities and competencies, primarily cognitive combat readiness. Likewise, gamers are always consistent in their learning styles and knowledge acquisition, giving them adaptive power for problem-solving, high reasoning power, responsibility to act, etc. Furthermore, this study explains that academic and vocational learning and training systems must be designed to bring students high cognitive work readiness. Thus, they will have solid skills and expertise to enter the workforce with adequate capabilities and competencies.

Limitations and future research

Having completed this research, the authors acknowledge weaknesses affecting the robustness of the validity of the conclusions. First, this study does not include the gamers' personalities, resulting in different learning styles and knowledge acquisition patterns. Then, it explains that gamers' characteristics, such as confront- and transform-proactive personalities, could affect other knowledge acquisitions resulting in high cognitive combat readiness. Finally, excluding gamers' personalities has consequences regarding the weakness of future research generalisation because character influences teammate loyalty, integrity, and patience. Second, this study's results deserve attention because they do not measure gamers' intelligence quotient. On the other hand, this study acknowledges that the intelligence quotient influences learning styles and knowledge acquisition. Likewise, the intelligence quotient constructs a different cognitive combat readiness, leading to more excellence. Therefore, future studies could complement this by establishing how the intelligence quotient determines gamers' learning styles and knowledge patterns.

Third, the authors recognise that this research method classifies gamers with a questionary design, impacting that we inferred the analysis results in affirmative biases. Meanwhile, we compared mean values of gamers' cognitive combat readiness as the consequenced measurements. Thus, it opens opportunities for future research to ascertain no affirmative biases using comparisons of gamers versus non-gamers, gamers versus other gamers, and non-gamers versus others. Finally, this study recommends setting gamers' self-control levels to make this future research more attractive. In essence, gamers' self-control indicates their maturity level in social life, which affects cognitive combat readiness. However, this research underlines that gamers' life-maturity levels result from their knowledge acquisition from past experiential values that will strongly dominate their attitudes and behaviours in the future.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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

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Supplementary material

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Face-to-face versus online-based lectures: A COVID-19 induced study on assessments

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Introduction: There is much debate regarding the impact of COVID-induced lockdown on the standard of assessments, mainly since students were assessed at home *via* an online assessment platform. Regular orthodox lectures and assessments were carried out during the first term, while the strictly enforced South African COVID lockdown warranted that 2nd term lectures and assessments were based online. This created the fortunate control conditions to statistically compare orthodox face-to-face with online-home-based assessments.

Methods: We compared the assessments of a cohort of second-year students studying physiology and anatomy during 2019 and 2020: Orthodox face-to-face teaching and assessments (2019) were compared to online teaching and their analogous online assessments (2020) during the COVID-19-induced lockdown.

Results: Although class pass rates and marks for online assessments (2020) were significantly higher than for traditional assessments (2019), an essential finding of the study was that the Gaussian distribution of the marks across the class for both modes of assessment was statistically identical. This indicated that although students performed better with home-based online assessments, poor-performing students populated the lower spread of marks, modal students occupied the central distribution, while good students occupied the higher mark distribution of the curve.

Discussion: The students were found to be resilient in adapting to things and learning, online presentations, and computer-based assessments. No gender-based difference or advantage to adjusting to newly introduced blended learning and concomitant changes in learning assessment strategies was found. The online-home-based assessments proved to incentivize prior learning and preparation for assessments by implementing strict time limits or assessments and randomizing the selections of questions and respective (MCQ) answer choices. We conclude that although home-based online assessments significantly improve the overall mark distribution, there was no distinction in the spread of the distribution of marks, which was indicative that the home-based online assessment process was able to provide an identical measure of

course proficiency as in the orthodox sit-down assessment. Therefore, our statistical analysis of the performance of students under student assessment performances indicates that there is no rationale for thinking that the home-based online mode of assessment is equivalent to or better than the orthodox modes of assessment.

KEYWORDS

blended learning, e-learning, assessment strategies, iKamva, home-based online assessments

Introduction

The COVID-19 pandemic has induced landmark changes to the way society, business, and education have normally operated (Donthu and Gustafsson, 2020). In a world under the constant threat of virus infections with high mortality, our mode of social interaction has altered dramatically. The tertiary landscape is not spared from the onslaught of the COVID-19 pandemic (Aristovnik et al., 2020; Hedding et al., 2020). Universities across the world closed their doors to students, and during the most severe infection trajectories, also to the research project, as labs were closed and postgraduate students were sent home (Marinoni et al., 2020; Motala and Menon, 2020).

COVID-19 has ushered in and accelerated the dawn of 4IR on the back-bone of high-speed internet connectivity (Mhlanga and Moloi, 2020), where offices and university classrooms have primarily become obsolete and rapidly replaced by home-based offices and classrooms (Mishra et al., 2020). This meant computer skills, technological infrastructure, learning resources, student and staff communication, assessments, and new (blended) modes of learning and teaching had become necessities (see, for example, the Complex Adaptive Blended Learning System (CABLS) framework suggested by Wang et al., 2015, and the recent article Jumaa et al., 2022).

In response, the tertiary sector rapidly mobilized staff to teach remotely, using the efficiency of virtual conferencing platforms (Microsoft Teams, iKamva, Zoom, Google Meet, Skype, Mentimeter, LT platform for physiology, etc.) while using established paper-based testing (PBT) moving to computer-based testing (CBT) to assess students. Rapanta et al. (2020) found that there is a need to design learning activities with specific social, cognitive, and facilitator characteristics, as well as the need to adapt the assessment to new learning requirements. Blended learning impacts the role and relationship of instructors and students and, consequently, learning assessment strategies. The COVID-19 pandemic, despite its myriad of setbacks, offers opportunities to modernize anatomy education approaches (Khasawneh, 2021). Although cadaver and laboratory education was disrupted (Özen et al., 2022), this challenge has highlighted the demand for blended learning and teaching environments that consist of some online offerings and some face-to-face classes. In Egypt (Mahdy and Sayed, 2021) early, two-thirds of veterinary anatomy students felt enthusiastic about online mode during the lockdown. Numerous studies (Mahdy and Sayed, 2021; Mahdy and Ewaida, 2022; Zarcone and Saverino, 2022) also recommend innovative measures, three-dimensional virtual tools such as Visual Body, and electronic devices such as Leica Acquire, to mitigate common problems associated with distance learning. Lima et al. (2020) proposed both synchronous and asynchronous activities using various online tools for essential topics in human physiology.

We attribute the overall performance of a cohort of second-year physiology and anatomy students in the second-year Medical Bioscience module MBS231 at our tertiary institution to this; i.e., students and teaching staff seem to benefit from online access to relevant course material. In addition, one could speculate that quality-assured learning environments have positive spin-offs over and above traditional face-to-face classes. In a study done by Paechter and Maier (2010) that involved 2,196 students from 29 Austrian universities, it was found that they appreciate online learning for its potential to provide a clear and coherent structure to learning material and that it supports self-regulated learning and distributing of information. They found that for understanding or establishing interpersonal relationships, students prefer face-to-face learning. Furthermore, students also appeared to prefer online learning for acquiring skills in self-regulated learning, but when it came to conceptual knowledge or learning skills to apply knowledge, students preferred face-to-face learning (Paechter and Maier, 2010). Online learning incentivizes students to become self-disciplined, study independently, engage in course materials independently, and prepare for exams, all of which provide a foundation for life-long learning.

Ideally, assessment security should remain uncompromised, so it is not surprising that e-proctoring has surged since the start of the COVID-19 pandemic (Flaherty, 2020). Mean scores and throughput rates remain broadly comparable across assessments, whether conducted with online proctoring at testing centers in the presence of proctors (García-Peñalvo et al., 2021). Institutions are adopting flexible multi-modal solutions to CBT, providing access

to CBT *via* a network of secure centers or their own homes, with options such as live online proctoring and record-and-review proctoring.

The University provided students with laptops and data for network connection to allow students to access the online material. Many students suffer from unconducive living conditions away from campus. Besides implementing COVID-19 regulations, a new policy on flexible learning and teaching provisioning had to be developed. In addition, a new learning assessment policy was drafted, all designed to regulate the academic project and to maintain outcome proficiencies while maintaining academic standards.

The initial set-up cost of CBT is offset by savings on item or production costs (Boevé et al., 2015), and fortunately, for a large cohort of students such as MBS231, there is an extensive database of assessment content available that can be randomized and supplemented at low additional costs. Immediate assessment score reporting has a largely positive impact on students' achievement emotions, too (Daniels and Gierl, 2017). A multi-modal CBT carries built-in flexibility that accommodates year-on-year changes in student cohorts, guaranteed safety, and instant adaptability to changes in COVID-19 protocols, and it has unlimited reach with less intrusion on test-takers time, as well as much greater accessibility than traditional assessment platforms. Such digital scoring saves time and resources (Seale, 2002).

This move from PBT to CBT is a means of providing greater access and less expediency, but there is still a need for understanding its impact, shortcomings, and ultimately how its design and delivery can improve, as was suggested by Guimarães (2017). This study on the impact of moving from face-to-face to digital assessment informs the validity and reliability of assessment scores in high-impact modules. We use statistical analysis to compare assessments of two cohorts of students (2019 to 2021) studying physiology and anatomy in a Medical Bioscience undergraduate program.

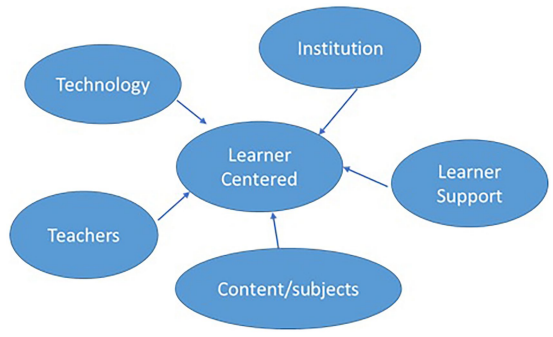

FIGURE 1
The conceptual framework of the Complex Adaptive Blended Learning System approach, which points to the learner-centered philosophy (Wang et al., 2015).

Theoretical framework

Developing an institutional online approach requires a skilful approach and full support to compensate for the face-to-face approach (Gregory and Lodge, 2015). Both systems favor the learner-centered approach philosophy: learners as active agents that bring knowledge, past experiences, education, ideas, and impactful new information to the classroom environment. A priority for a thriving online environment is that the instructor needs to transition into an effective online communicator, manage technology, and deliver and assess online content (Roddy et al., 2017). Monitoring students' progress, engaging students *via* online platforms, doing follow-up consultations, and flipping the class is crucial for a vibrant online environment. Some instructors are new to blended environments and have to adapt rapidly to new teaching modalities. They now provide constant support *via* the online environment to monitor student progress, resolve learning queries, and provide access to collective competencies of the online learning experience.

Therefore, to support the blended learning approach, it is vital to consider Complex Adaptive Blended Learning System (CABLS) framework (Wang et al., 2015), illustrated in Figure 1. Within this framework, the student is located at the center of the model, with the relevant satellite components all impacting one another (Figure 1).

This philosophy is based on the learner being the central role-player, as illustrated in Figure 1. Thus, the blended learning strategy is geared toward supporting and training students for lifelong learning and identifying essential pedagogical needs of students pertaining to the 21st-century society. The role of the student is to adapt as they interact with system elements for the first time or in new ways.

As blended teaching and learning environments require significant investment and capital layout in technology (see Figure 1), equipment, and sophisticated networks to sustain the tertiary capacity to maintain academic standards and student performance, tertiary institutions could not rely on governments to bail them out. Fortunately, our institution has the iKamva platform, which is user-friendly to both staff and students and is integral for online learning, teaching, and CBT.

The transition from face-to-face to online learning technology played a crucial role for lecturers to provide much more effective communication between staff and students and students in the online learning environment. Communication modalities such as email, chat, live class questions, online assessment, and feedback provision have turned the MBS231 classroom environment from a passive into an enriching active one for students and lecturers. This is in line with what Wang et al. (2015) refer to as learner support.

The module MBS231 is a core module for the BSc Medical Bioscience degree. Online assessment has come under increasing scrutiny due to emerging perceptions of quality assurance and the ability to reflect on performance outcomes (Newman, 2015). There still needs to be more clarity between quality assurance

indicators and the quality of online and blended learning approaches (Openo, 2017). The perception that online learning is not as effective requires an urgent response since it and blended learning approaches have become a critical 21st-century skill (López-Pérez et al., 2011; Vaughan, 2015; Conrad and Openo, 2018), so tracking student performance in MBS231 should be viewed in this light. In line with Wall, Hursh, and Bond (2020, p.6), assessment tasks are a "set of online activities that seek to gather systematic evidence to determine the worth and value of things in higher education." Students' submission of assessment tasks in MBS231 is the most telling indicator of the quality of educational outcomes (Gibbs, 2010, p. 7). It provides evidence of the learning outcomes for accountability and quality assurance (Conrad and Openo, 2018, p. 5).

The study aims to compare and analyzes the assessment data of second-year Physiology and Anatomy students (MBS231) between traditional face-to-face classroom lessons in 2019 to full online modes of learning and assessment, the latter enforced by the advent of the COVID-19 pandemic in March 2020. Presented with an opportunity to fully engage with online learning and teaching pedagogy, together with a full suite of online assessment modalities, we challenge the premise that there is a discernible distinction between assessment standards in the second-year Medical Bioscience module with home-based online assessment by comparing results to the traditional sit-down form of assessment. We describe an online learning environment that is much more transparent and responsive to students' learning needs, and when conducted effectively, it incentivizes learning, thereby addressing quality assurance. Assessment strategies are strongly aligned with pedagogical practices in MBS231 through blended learning approaches catered for by in-person and online spaces for learning and teaching. This point is demonstrated in the methods of assessment described below.

Methods

Participants

Participants were second-year undergraduate students ($N = 398$) in the Department of Medical Biosciences (MBS) at the University of the Western Cape in South Africa. They were drawn from two cohorts of module MBS231 in the year 2019 ($n = 197$), which was a traditional assessment and 2020 ($n = 201$), which was an online assessment. Both cohorts were multidisciplinary and ethnically diverse. Assessment marks of the 2019 sit-down (SD) examination and the 2020 online examination are taken into account. Both cohorts consist of male and female students. The 2019 data set consisted of ($n = 68$) males and ($n = 129$) females. The 2020 data set consisted of ($n = 58$) males and ($n = 143$) females. Age ranges from 18 years to 30 years old. Data were analyzed using Graphpad Prism (version 5, San Diego, California, USA).

TABLE 1 Demographical data of 2019, 2020, and 2021 student groups.

MBS231 Demographic	2019	2020	2021
Class size	197	201	223
Number of females	129 (65.5%)	143 (71.1%)	152 (68.2%)
Number of males	68 (34.5%)	58 (28.9%)	71 (31.8%)
Class average age	21.38	21.07	20.82
Class average age (males)	21.46	21.15	21.04
Class average range (females)	21.35	21.04	20.72

Sakai (iKamva) platform

The institutional e-learning content management system Sakai (iKamva) is built using responsive web design principles that allow users to access the platform from multiple devices (with internet connectivity) at any geographical location. Table 1, obtained from UWC CIECT (2020), reflects the total number of unique users logged in from mobile devices (not using the app), computers/laptops, and the iKamva Android application.

The UWC Faculty of Natural Sciences cooperates closely with CIECT in arranging blended learning approaches and plans for students and staff during the national lockdown in South Africa (UWC NSCI, 2021).

CIECT offers training to lecturers and students using iKamva to supplement traditional learning (face-to-face lecturing) and for online teaching and assessments. iKamva has various e-Tools used to deliver the program, such as announcements, course resources, tests, quizzes, assignments, discussion forums, and structured lesson tools. Sakai (iKamva Platform) has been ranked the top Open-LMS since 2019 to date.

Traditional assessment format

During 2019 both practical evaluations were conducted in the traditional sit-down manner, while in 2020, practical evaluations were both conducted as home-based online assessments due to the COVID-19 lockdown. Practicals were carried out as conventional teaching laboratory hands-on practicals in the first term of 2020, while practicals in the second term were based on narrated PowerPoint presentations augmented with mostly YouTube-based videos which replaced the laboratory hands-on component of the practicals. Practicals were then assessed *via* the home-based online assessment platform every second week, and these assessments formed the basis for the final practical evaluation mark of Term 2. In both practical evaluations 1 and 2, the distribution of the practical arks, and consequently throughput significantly improved for the online assessments in 2020 when compared to 2019.

Traditional assessments and examinations were based on face-to-face lessons. Module lecturers prepared a set of exam questions

according to Bloom Taxonomy guidelines (Anderson et al., 2001). The question paper consisted of 13 marks multiple-choice, 12 marks for true/false, and 25 marks for short essay questions. A set percentage of questions were knowledge-based questions, and a smaller number of questions were based on an application, integration, and analytical basis. Sit-down assessments written under traditional assessment conditions were hosted in large examination venues. A question paper counted 50 marks within a 90-min time frame and was written on answer sheets collected for marking afterward.

A multiple-choice type question of no more than 5 answer choices carries a penalty of-0.25 for a wrong answer, with no reason or justification required for an answer. A True/False type question counts 1 mark with a penalty of-0.5 for a wrong answer (no reason or justification required for the answer). Only one test or exam submission was allowed. In the event of electrical load-shedding, or due to challenges involving a shortage of data and internet connectivity, the student was required to obtain an affidavit from the police station. A completely new assessment randomly generated from pools of questions would then be issued to the student. Question types (MCQ, T/F, short/long answer) were identical for traditional assessments in terms 1 of 2019 and 2020/2021. The assessment format was orthodox in Term 2 of 2019 (MCQ, T/F, and short/long answer) and online *via* iKamva in Term 2 of 2020/2021 (MCQ and T/F types only). Of the online iKamva assessments in Term 2 of 2020, 20% are difficult questions, while 40% are intermediate questions, and the remaining 40% are easy.

Home-based online assessments

The home-based online assessment started at the beginning of Term 2 in 2020/2021, as South Africa went into lockdown (Carlitz and Makhura, 2021) due to the COVID-19 pandemic. Although the 2020 cohort wrote their first assessments during Term 1 in an orthodox manner, and Term 2 was an online assessment. The continuous assessment (CE) mark counts 50% toward the final mark (FM), and the final exam counts 50%. The Jue 2020/2021 Final Examination papers, Paper 1 and Paper 2, were based on work covered in Term 1 and Term 2, respectively. Assessment standards were maintained and all assessments were moderated internally. Assessment questions covered all content completed in lectures and textbook-based coursework. Most questions were application and integration of knowledge and understanding, and a few were purely knowledge-based.

Pools of questions were designed using the iKamva assessment platform. Each assessment and examination contained 30 multiple-choice and 20 true/false questions randomly selected from a database of 200 multiple-choice questions and 200 true/false questions designed for each event. The iKamva platform randomizes answers per question, and it randomizes questions. A randomized set of questions is thus generated for each student to minimize peer-to-peer consultation and copying (Olt, 2002). Every assessment had a time limit that was strictly implemented, providing on average 1.5 min per question. This further incentivizes preparation, as searching for answers would take up an inordinate amount of time. Each answer counted one mark. An incorrect true/false answer accrued a-0.5 penalty and every incorrect MCQ answer accrued a-0.25 penalty.

Statistics

The data was analyzed using the software program GraphPad Prism (version 5, San Diego, California, USA). Box and whisker box plots were used to present the distribution of assessment marks (%) the box represents the lower and upper quartile, the center-line in the box represents the median (or quartile 2) and the whiskers represent the minimum and maximum values of the range of assessments.

Before statistically comparing two sets of data, a Kolmogorov–Smirnov test (Kolmogorov–Smirnov test in GraphPad Prism; Massey, 1951; Corder and Foreman, 2014: p. 26) was carried out to assess if the data were normally distributed ($p > 0.05$). If both sets of data were normally distributed then an unpaired *t*-Test (Graphpad Prism: unpaired *t*-Test; Ekstrøm and Sørensen, 2019: p. 153; Corder and Foreman, 2014: p. 57) was used to determine if the means were significantly different, otherwise for non-normally distributed data ($p < 0.05$), a Mann–Whitney statistical test was used (Graphpad Prism: the Mann–Whitney test; Corder and Foreman, 2014: p. 57). Differences were considered significant when *p*-value <0.05.

Results

Controls

Any study involving comparisons is only as good as the control set of data to which it will be compared. In this study, we compare 2019, 2020, and 2021 assessment data using a cohort of students registered in the course MBS231. In first comparing 2019 data with 2020, we ask two fundamental questions: are the data sets equivalent statistically and demographically, and if they are, how do the two modes of assessment (traditional versus online assessment) compare regarding the mark distribution. We then compared traditional assessments (2019) with selected home-based online assessment results between 2020 and 2021 to evaluate if the home-based assessments were different from the orthodox 2019 assessments, and if different, could statistical analysis provide insights into the differences. It must be pointed out that the essential difference between the 2019 and the 2020 cohorts of students, was that 2020 students were assessed during a very strict lockdown in South Africa, regulated by the South African armed forces which limited the movement of individuals to their homes. In contrast, in 2021, the lockdown was abandoned and individuals were free to liaise with each other, although a 10 pm national curfew was still enforced strictly.

The implicit assumption is that the control samples (student groups in 2019 and 2020) we are comparing are statistically similar. If they are statistically dissimilar it would nullify further comparison. We, therefore, interrogated these assumptions made before we compare the data from these two cohorts of students: firstly, the groups of students are second-year students, all familiar with academic processes, and have settled into the rigors of academic discipline, having overcome most of the challenges typically presented a student's first academic year. Thus, we are presented with a more mature, homogenous group of students at the second-year level than at first-year levels, whereas educational, urban versus rural, financial, and cultural backgrounds play a crucial role in the variance of success of first-year students. The demographics of class size and the difference in the size of gender groups between the 2 years was less than 5% (see Table 1).

The demographics of our cohort of students for Physiology and Anatomy (MBS231) were also similar to the global demographics for veterinary Anatomy students surveyed during the COVID-19 pandemic (Mahdy and Ewaida, 2022). In this study, there were also more female students than male students and 80% of the student's ages ranged between 18 and 25 years of age. Although the demographics between the two classes were very similar (see Table 1), we wanted to establish whether, under the same assessment conditions, the distribution of assessment marks between the two groups was indeed statistically equivalent. Establishing statistical normality between MBS231 student groups in 2019 and 2020 would be essential to compare traditional and home-based online assessment data between the two groups, in other words, should the statistical distribution of marks differ significantly in term test 1 (same assessment conditions for both 2019 and 2020), it would nullify further comparisons between the 2019 and 2020 groups of students.

In brief, both sets of students were exposed to traditional face-to-face (F2F) lectures, followed by an end-of term sit-down (SD) assessment. We statistically compared the 2019/2020 assessment data for the first theory tests using box-and-whisker plots and Gaussian distribution curves. The box-and-whisker plots in Figure 2A show the distribution between the two groups of students was not statistically different ($p < 0.1$). This is confirmed by Gaussian distribution curves superimposed on the overlaid histograms of both sets of data ($p < 0.1$). This endorsed the postulate that both sets of students were statistically identical from an assessment perspective. Thus, there was no reason to believe that these students would respond differently in other assessments of the module. We, therefore, established that the 2019 group of students was statistically similar to the 2020 cohort of MBS231 students by comparing their theory test 1 assessment data ($p < 0.1$). There was no difference in both tuition or assessment conditions for theory test 1 for these two groups of students, as COVID lockdowns in 2020 were introduced after this assessment. We, therefore, concluded that the 2019 assessment data would provide an acceptable set of control data to which we could compare the 2020 home base online assessment data.

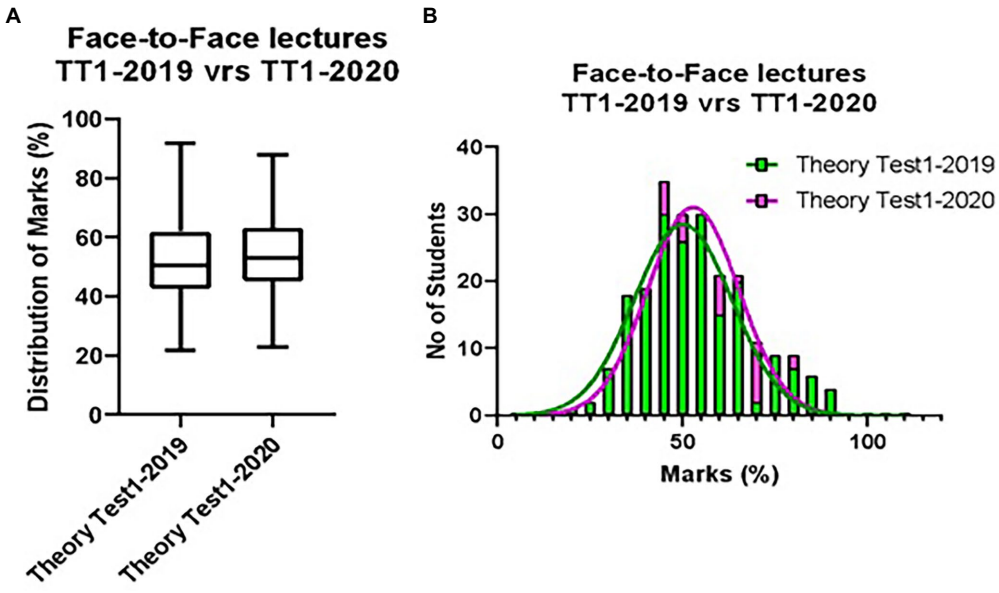

FIGURE 2
Graph **A** depicts the distribution of marks for theory test 1 (Term 1) for both 2019 and 2020. Both sets of students were presented with face-to-face lectures, and both groups were assessed using the traditional "sit-down" assessment format. Theory test 1 was not normally distributed, and therefore, the nonparametric Mann–Whitney statistical test (Graphpad Prism: the Mann–Whitney test; Corder and Foreman, 2014: p. 57) showed that there were no significant differences between the means of these sets of data (p<0.1). Graph **B** presents the same sets of data using Gaussian distribution curves superimposed over the frequency distribution of the two sets of data. The data shows that both the 2019 and 2020 groups of student assessment data were equally distributed (p<0.1). The abbreviation refers to the Theory Test.

Traditional assessments versus home-based online assessments

Given the control assessment data showed that the first theory test was statistically identical ($p < 0.1$; Figures 2A,B), we evaluated the impact of COVID-induced online teaching and online home-based assessments (in 2020) on the distribution of marks, and compare them to the analogous periods of traditional teaching and assessments in 2019.

Theory Test 1/2 (2019): In Figure 2A, we firstly compare Theory Test 1 (2019) to Theory Test 2 (2019). Both these assessments were carried out under the same traditional teaching and assessment procedures. Statistical analysis showed that Theory Test 2 presented a distribution of marks that was slightly, but significantly lower, than the first theory test ($p < 0.0001$).

Theory Test 1/2 (2020): In Figure 2B, Theory Test 1 (term 1: 2020) was carried out under orthodox teaching and assessment methods, while Theory Test 2 (term 2: 2020) was carried out under COVID-19 lockdown conditions, and thus all narrated lectures were given online and assessed using the iKamva home-based-online assessment platform. The distribution of marks in Theory Test 2 (2020) was significantly higher ($p < 0.0001$) than in the orthodox SD assessment in the first term.

In Figures 3C,D, we used superimposed Gaussian distribution curves over the histogram distribution of the data to confirm the statistical differences seen in Figures 3A,B ($p < 0.0001$).

The theoretical work in term 1 is firstly examined during Theory Test 1, and then it was comprehensively assessed in Exam Paper 1. This is the same for term 2, where the coursework was firstly examined in Theory Test 2, and then comprehensively assessed in Exam Paper 2. The final exam mark (%) is the average of these two exam papers.

Theory Test 1/2 verses Exam Paper 1/2 (2019): The distribution of the marks (%) in Theory Test 1 was not significantly different from Exam Paper 1 (Figure 3E). However, although the distribution of the marks in Theory Test 2 was lower than in Theory Test 1, in the corresponding Exam Paper 2, the mark distribution was significantly higher ($p < 0.0001$).

Theory Test 1/2 verses Exam Paper 1/2 (2020): During 2020, only term one was carried out it traditionally with regard to teaching and assessments. From term 2, all lecturing was based online as well as assessments (this also took place during COVID-19 lockdown). The distribution of marks for both exam papers was significantly higher than for the theory tests ($p < 0.0001$; Figure 3F).

Distribution of theory test 2 assessment marks

We wanted to investigate whether students were adapting to the online assessments from 2020 to 2021. Gaussian curve analysis showed that the distribution of assessment marks for Theory Test 2 in 2020 and 2021 was not statistically different (Figure 4). It must be noted that these two successive cohorts of students were almost identical in terms of demographics (See Table 1). Given the statistical equivalence in the kurtosis of the mark distribution ($p < 0.1$), the difference in the heights of the curve peaks of the distributions is determined mostly by the variance in student numbers (see Table 1). However, the mean and mode of the 2020/21 distribution curves are statistically equivalent ($p < 0.4$).

Throughput of MBS231

The throughput rate (TP%) of a module refers to the percentage of registered students that pass the module (obtaining 50% or more in an assessment). TP% is one of the most used performance indicators in Higher Education (Scott et al., 2007; Yeld, 2010; Bozalek and Boughey, 2012). The distribution of these data sets normally skews to the rightgiven that under traditional assessment conditions more students tend to pass than fail, where the mode/medians are normally between 55 and 75%.

During 2019 both practical evaluations were conducted in the traditional sit-down manner, while in 2020 practical evaluations were both conducted as home-based online assessments due to the COVID-lockdown. Practicals were carried out as conventional teaching laboratory hands-on practicals in the first term of 2020, while practicals in the second term were based on narrated PowerPoint presentations augmented with mostly YouTube-based videos which replaced the laboratory hands-on component of the practicals. Practicals were then assessed *via* the home-based online assessment platform every second week, and these assessments formed the basis for the final practical evaluation mark of Term 2. In both practical evaluations 1 and 2, the distribution of the practical marks, and consequently, TP significantly improved for the online assessments in 2020 (Figures 5B,D) when compared to 2019 (Figures 5A,C). The TP for Theory Test 1 and 2 for 2020 was significantly higher when comparing analogous TP in 2019, with the TP of 93% for Theory Test1 (traditional sit-down assessment) and 92% for Theory Test 2 (online lectures and online assessments), did not differ statistically. Gender differences?

We wanted to investigate if there were any gender differences between the assessment distributions. This is an important consideration in light of studies showing that computer self-efficacy and anxiety do impact computer-based test performance, which was found to be more pronounced in female undergraduate students (Balogun and Olanrewaju, 2016). We found that both genders' data subsets correlated well with the distribution for the combined assessments, *viz.*, that if the total assessment improved or decreased, both male and female data subgroups contributed equally to that change (Figures 6A–F).

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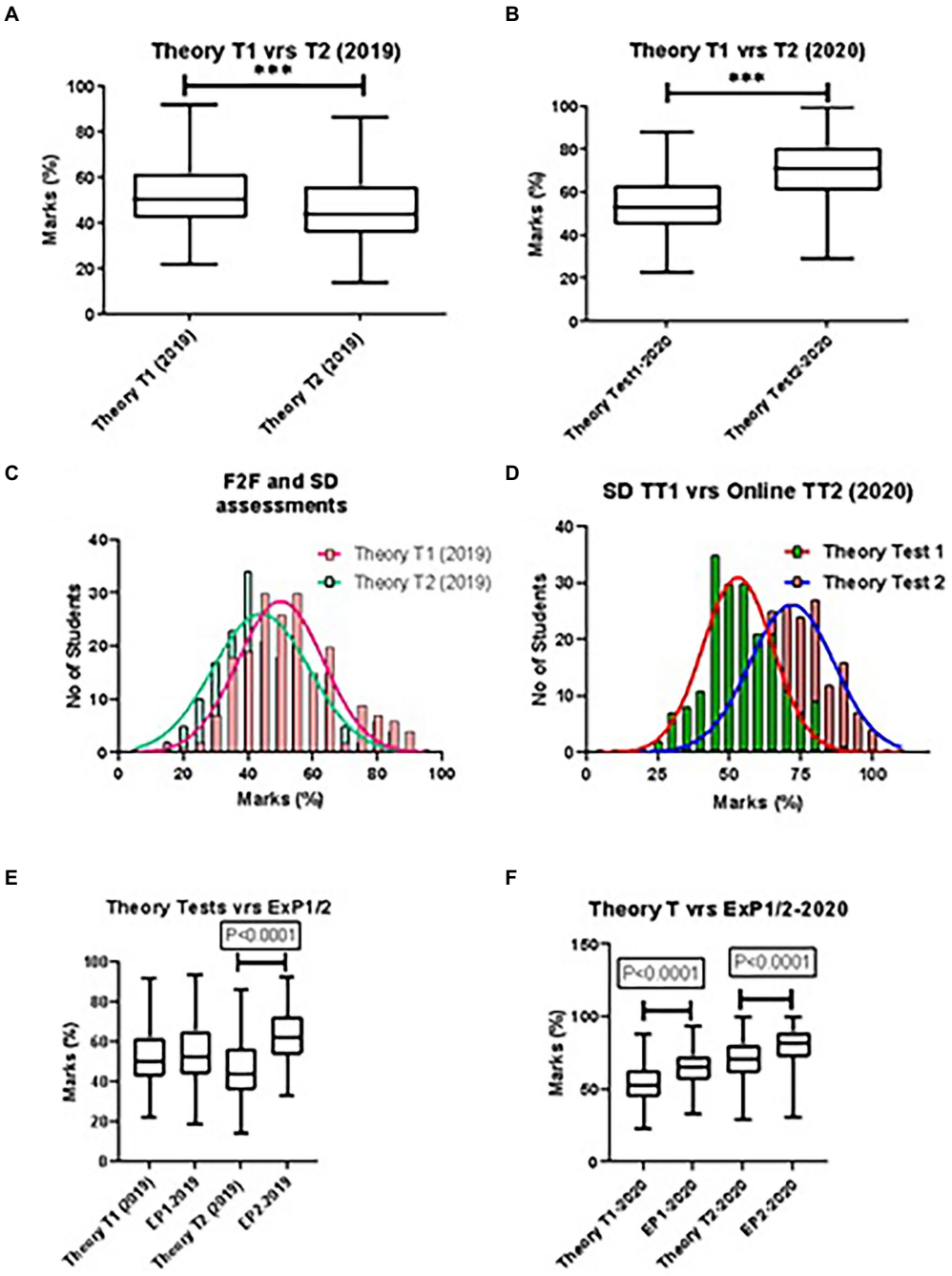

FIGURE 3
(A) The assessment data (2019) represents normal F2F lectures and orthodox sit-down (SD) assessments. Theory Test 2 had lower Quartile groups 2 and 3, including a slightly lower median; statistical analysis showed that these sets of data were statistically different from each other ($p<0.0001$). **(B)** Here, we compare the analogous data sets in 2020, where Theory Test 1 was an SD assessment compared to an online home-based assessment. Statistically, the online assessment had a significantly higher distribution of marks (%; $p<0.0001$). **(C,D)** Here we show the analogous sets of data (to **A** and **B**, respectively) using Gaussian distribution curves superimposed on frequency distributions of the two sets of data. **(E,F)** "B and W" plots are used to statistically compare Theory Test 1 (T1) with the analogous Exam Paper 1 (EP1) and Theory Test 2 (T2) with the analogous Exam Paper 2 (EP2). In 2019, there was no significant difference between Theory Test 1 and Exam Pape; however, the distribution of exam assessment percentages was significantly higher in Exam Paper 2 (EP2) compared to Theory Test (T2). In 2020, in both comparisons, the distribution shifted to the right in exam assessment percentages was significantly higher than in the term tests.

We analyzed the assessment data to investigate whether male students adapted faster to the online experience compared to female students or vice versa. Based on the assessment distribution, we found no statistically significant differences in how the different gender groups adapted based on gender subgroups (Figures 6E,F).

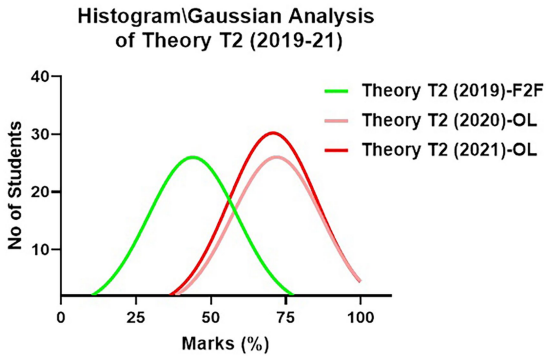

FIGURE 4
Gaussian statistical analysis shows that the distribution of marks for the online assessment of Theory Test 2 remained statistically equivalent (p<0.2) for two different sets of students (2020 and, 2021). This indicated that in successive years (2020 and, 2021), standard, home-based online assessments were able to successfully grade different cohorts of MBS231 students according to their proficiency in the theoretical components of the course.

Discussion

The choice of controls

There is a saying in experimental science "that any experiment is only as good as the control." Fundamentally, this truism can be extended to any set of data that you would like to compare. We wanted to analyze assessment data sets in which traditional face-to-face (F2F) teaching in 2019 and compare it with online teaching and assessment data. Coincidentally, we wanted to assess the impact of the COVID-19 induced-lockdowns on assessments, using a group of students in the Life Sciences (studying Physiology and Anatomy).

To compare the data in 2019 with the data in 2020, we had to evaluate how closely the two sets of students performed in the first-term assessment under traditional teaching and assessment conditions. These two groups of students were both second-year students and had similar demographics relating to class size, gender distribution, and age (see Table 1). Second-year students are fairly computer literate and display proficiency in a wide range of skills required for online learning, acquired in their first year of study using the same assessment platform (iKamva). While there have been many reports of challenges in the second-year experience (Graunke and Sherry, 2005; Fisher et al., 2011; Conana et al., 2022), these students are better oriented to strive toward establishing identity, competence, deeper learning, and goal setting compared to first-year students. Thus, from a demographic background as well as a preparatory point of view, these two sets of students were virtually identical.

We wanted to evaluate, from a traditional assessment perspective, whether this similarity between the two groups of students would still exist. Our statistical analysis of the assessment data for 2019 and 2020 (Figure 2), showed that these two sets of data were not significantly different from each other (p < 0.1). The Gaussian distribution curves in Figure 2B further endorses this evaluation, showing symmetrical distribution between the two data sets. This statistical analysis strongly suggests that both sets of students, as per the evaluation of their assessment scores, are statistically identical. This would therefore provide a solid foundation or baseline to compare assessments between both orthodox and online teaching and assessment methods. Zarcone and Saverino (2022) assigned students from the same cohort in the same term randomly to either a computer-based or a paper-based test consisting of the same questions to measure test-mode effects and found that the group assigned the computer-based test outperformed the group who attempted the paper-based test. Although our design is different from Zarcone and Saverino (2022) in that during pre-COVID conditions, all assessments were evaluated using paper-based tests, while COVID-induced lockdowns precipitated the online assessments, the distribution of marks from online assessments were increased by an average of 16%.

The impact of online teaching and assessment

Given that both the 2019 and 2020 groups of students were statistically identical for Theory Test 1 (Term 1), we would expect that assessment data profiles should also be similar for Theory Test 2. Thus, differences between the statistical assessment profiles of 2019 and 2020 would be indicative of online teaching and assessment. We show that in 2019 there was a slight but significant decrease between the Theory Test 1 and Theory Test 2 assessments (Figures 3A,C; p < 0.0001). As the course content did not change and students were exposed to the same coursework, the assessment outcome in 2020 would be expected to be similar. However, we see that the assessment profile for Theory Test 2 (2020) significantly increased (Figures 3B,D; p < 0.0001). These observations are contrary to the findings of Prisacari et al. (2017) who found no significant difference in performance between paper-based and computer-based chemistry practice. This could potentially be a phenomenon similar to that observed by Omar et al. (2021), which revealed the effects of test score inflation in unproctored conditions.

An obvious question is what component of the increase in the assessment profile is due to the online teaching, and what component is due to the home-based online assessment? During the first term, the practical component of the course was taught using the traditional method. However, due to the COVID-lockdown, this component of the module was assessed using the home-based online assessment method. The 2019 assessment profile showed that Practical Evaluation 1 (PE1) was not statistically different from theory Test 1 TT1 (Figure 3E; p > 0.05). In 2020, PE1 was significantly increased compared to TT1 (Figure 3E). As practical coursework for both 2019 and 2020 was done using the identical traditional method the higher marks for

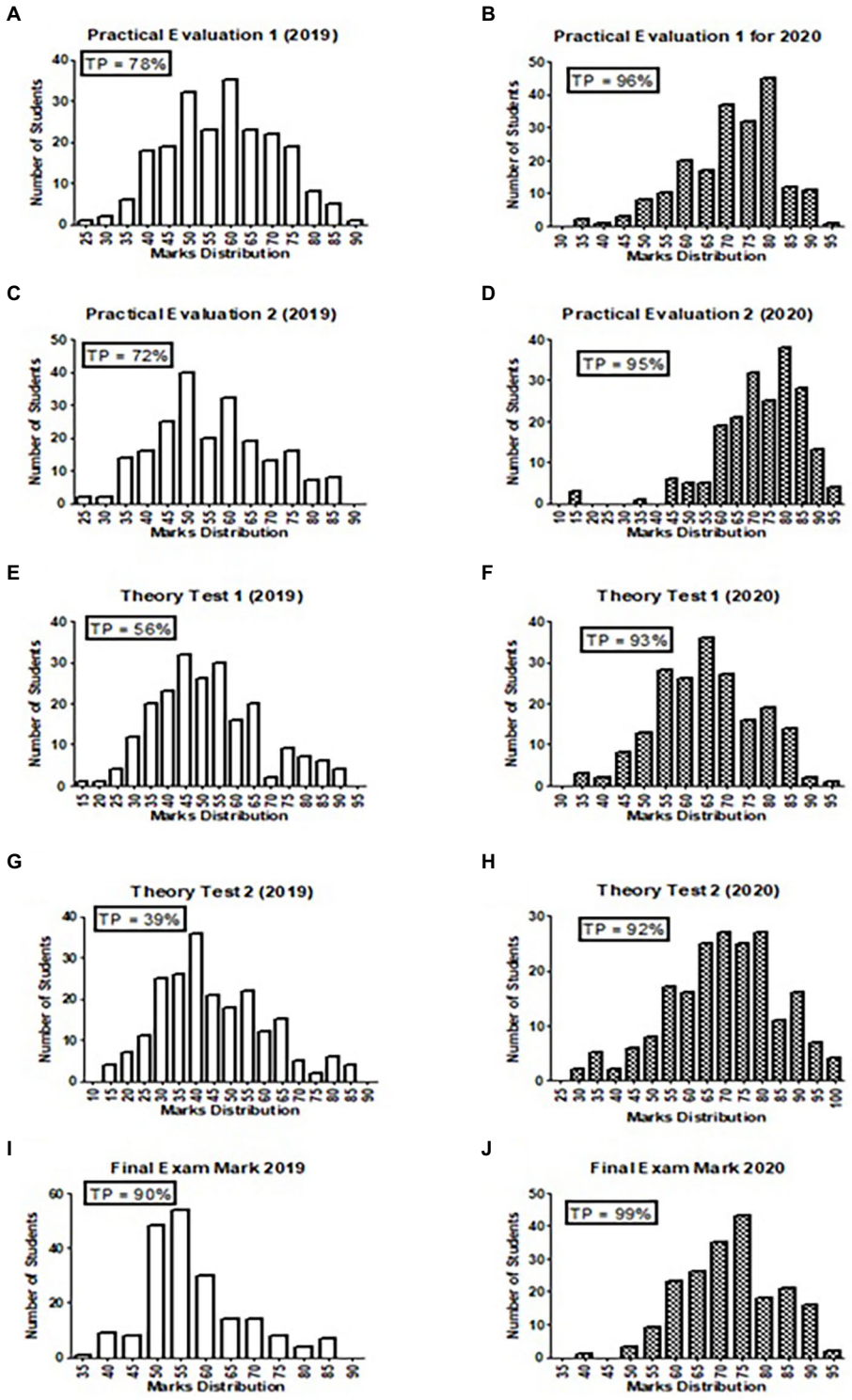

FIGURE 5
The following graphs depict the marks (%) distributions for all practical **(A-D)**, theory **(E-H)**, and exam assessments **(I,J)**. Each assessment event depicts the percentage of students in the MBS231 course that achieved more than 50% (TP).

the 2020 assessment suggest it was because of being a home-based online assessment and therefore may be weakly indicative of the differential impact of home-based online assessments. On the other hand, being assessed in an environment in which anxiety is decreased, is well known to improve assessment scores. We would also like to indicate that given the time constraints for each online

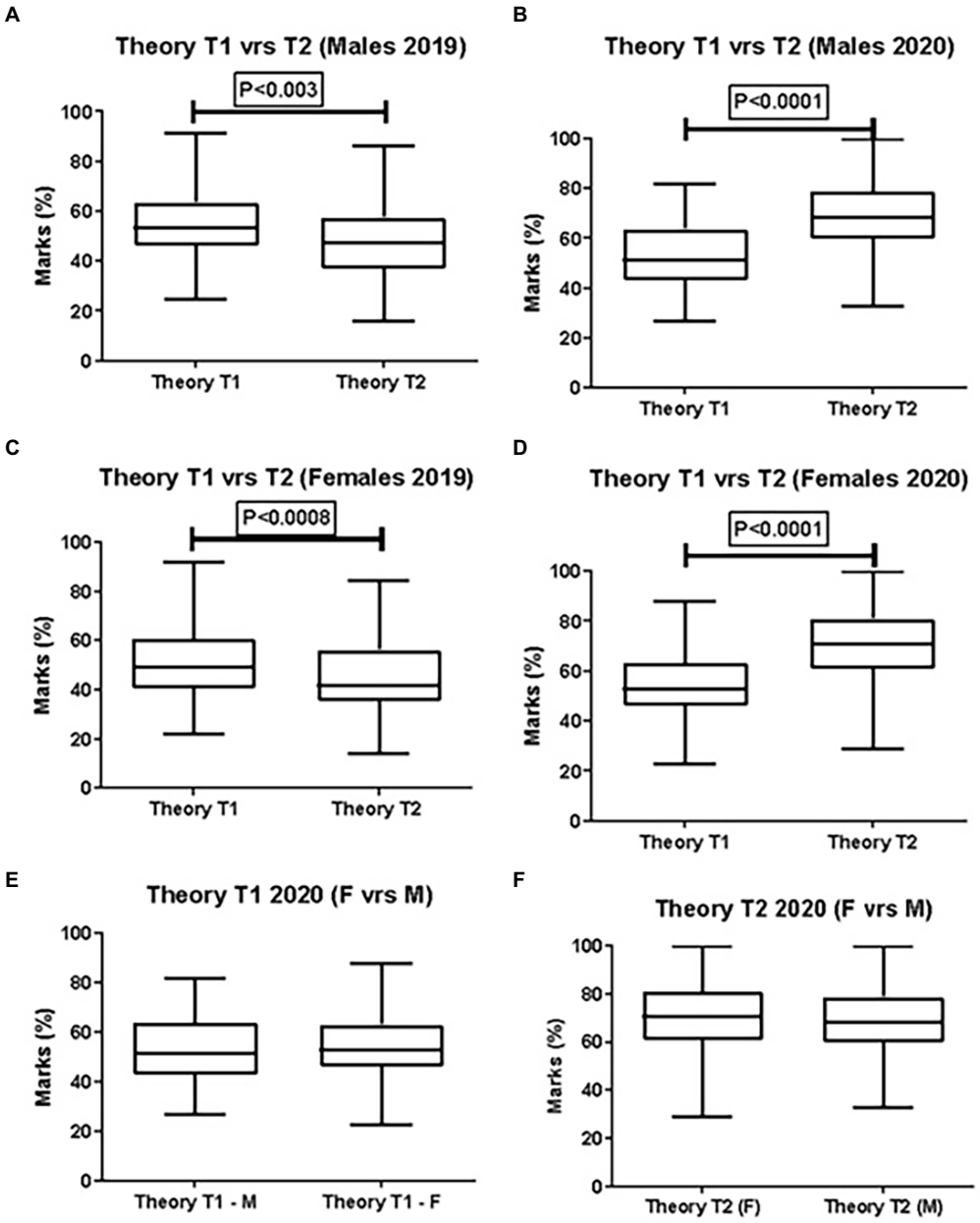

FIGURE 6
The graphs above present comparisons between the data gender subsets, and we compared the distribution of marks (%) for these subgroups of males **(A,B)** and females **(C,D)**. The distribution comparison between males and females is presented in graphs **E**, and **F**. Theory Tests (T) for 2019 and Theory Test 1 in 2020 was assessed in the normal sit-down method, while Theory Test 2 was a home-based online assessment of online lectures (COVID-19 lockdown period).

MCQ question (<1 min), students who would choose to search Google/PDFs/PowerPoint presentations for the correct answers, would find that they have compromised their chances to complete the assessment in the allocated time, by inadvertently losing assessment marks in the process. This in itself would incentivize students to prepare for assessments.

However, analysis of the assessment between TT2 and PE2 suggests that to discriminate between the effects of online teaching and online assessment, more data samples are needed to be conclusive: In 2019 (term 2), students performed significantly better in their PE2 than in their TT2 (Figure 3E). This same trend was observed between PE2 and TT2 in 2020 (Figure 3F). This made it difficult to discriminate what proportion of the increase in the marks profile was due to online teaching and/or online assessment. Nevertheless, it was clear that the marks profile had substantially and statistically improved for all online components of the course as compared to the traditional program in 2019.

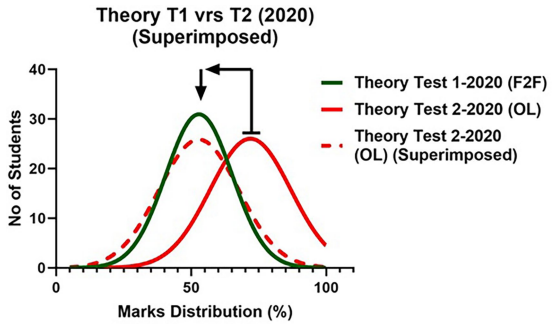

FIGURE 7
The statistical comparison shows that the shape (kurtosis) of the online marks distribution of Theory Test 2 was statistically not significantly different ($p<0.1$) from the shape of distribution of marks in theory test 1 (Face-to Face): We superimposed the two sets of data: Theory Test 1 (F2F) and theory Test 2 (OL). F2F: orthodox assessment; OL: home-based online assessment.

Interpretation of the Gaussian curves

A key feature of the Gaussian distribution curves was that the shape of the curves was not affected by online assessments (Figure 7). In fact, the curve was slightly flatter (not statistically significant), which indicated a broader distribution of the assessment data. This indicated very clearly that students that were at the lower end of the distribution curve (as per traditional assessment marks) remained at the lower end of the curve for home-based online assessments, and students that were above-average performers remained at the high end of the curve, with the majority of students centrally distributed on the bell-shaped curve. In other words, the distribution curve for online learning simply moved to the right. This further indicates that should the standard of the assessment been implicated, in other words, had the assessment had been made so easy, with most of the students easily passing the assessment, the shape of the curve would have changed distinctly by being skewed sharply to the right, and the shape of the curve would have also been very much steeper, all of which would indicate that any student in the class would have little trouble obtaining a high mark. The distribution curves of the home-base online assessments show that students were normally distributed ('bell-shaped curve'), clearly separating weaker, moderate and good students in all online assessments according to their proficiency in the theory component of the course. This unexpected outcome is both novel and crucial to future comparative evaluations of traditional SD and home-based online assessments.

We wanted to evaluate if the home-based online assessment trends during 2021 would be impacted by the evolving socio-political COVID pandemic environment, given that students could now freely move about, meet up at campus, access the library, etc., which was distinctly different to the 2020 socio-political lockdown environment. Furthermore, we wanted to evaluate whether students would adapt to the assessment methodology, by improving their marks, as would be demonstrated by a shift of the marks-distribution curve to the right, or a skewing of the distribution curve to the right. However, this was not the case, and it was surprising to see that the 2020/21 distribution curves were statistically identical (Figure 4). The significance of this is that our assessment process seems to be sustainable in terms of its accuracy in grading students according to their theoretical proficiency. This is borne out by the statistically equivalent distribution curves for 2020/21, that the spread (range) of marks (2020: 29%–100%; 2021: 31%–100%), graded students according to their theoretical proficiency. It infers that the procedural measures we have imposed on home-based online assessments, such as a limited time to answer MCQ questions, randomized questioning from large pools of question banks, and randomizing the answer choices for MCQ questions, provide a limited time for students to query MCQs *via* Google, PDF notes, video-based lectures, as these are time-consuming, and would eventuate in the student forfeiting completing the assessment, as the assessment automatically submits at the end of its allocated time. Although there are few recent studies that compared the distribution of student assessment marks before and during the COVID-pandemic, Saverino et al. (2021), used a similar cohort of students (anatomy) and compared their assessment distribution before and during the COVID pandemic (Saverino et al., 2021). Their assessment data supported our finding in also showing that the distribution of marks for online teaching and assessment improved relative to traditional teaching and assessments. Their distribution of online assessment data further endorsed our postulate that although assessment data for online assessment was improved relative to traditional assessments, the distribution of low to high marks remained very similar to the distribution of marks obtained during pre-pandemic traditional assessments.

The effects of online teaching/assessment on through-put (TP)

Administrators of tertiary institutions are fond of the variable TP, which indicates the percentage of the class which achieved 50% in assessments and therefore passed as opposed to that percentage of the class that failed. However, when used on its own it represents a very "blunt instrument" to analyze the assessment performance of a cohort of students. It says little about the distribution of data especially in terms of mode, median, and means, or the kurtosis of the distribution curve, etc. Nevertheless, it was interesting to consider TP relative to the effects of online assessed courses compared to traditional assessment methodologies (Omar et al., 2021). For a more informative discussion, we combined TP with distribution histograms to describe the distribution of marks for the class (see Figure 4). The TP range for orthodox teaching and the various assessments (2019: Figures 5A,C,E,G) ranged between 39% and 90% (for the Final Mark for the module), while in 2020 all TPs for online models ranged between 92% and 99% (Final Module TP

Percentage). Also, the kurtosis of the distribution of 2019 Theory test marks was on average more negatively skewed (skewed to the left), while for the 2020 Theory Test online assessments the kurtosis of the distribution was bell-shaped and shifted to the right, indicative of the higher TP values for online offering and assessment. Two anomalies appear in this data, firstly, the TP for Theory Test 1 (2019) was much lower than Theory Test 1 (2020), although both were taught and assessed in the traditional manner (this improvement may be due to the introduction of an experienced professor to teach the neurology lectures in the first term). Secondly, although the continual evaluation (CE) components (Theory and Practical assessments) of the course in 2019 had much lower TPs than their associated CE assessments in 2020, the final TP for the module differed by 9% (2019: 90% versus 2020: 99%). Essentially, the number of students who had achieved proficiency within the module improved by 9% under COVID-19 lockdown conditions.

TP of CE assessment events are much more critical to academic planning compared to the TP of final marks (%) of a course module. We compared the final throughput rates between 2019 (90%) and 2020 (99%) and were surprised that final throughputs differed by only 9%. Although this difference was small, it was statistically significant and translated to 18 more students passing in 2020 (Figures 5I,J). Finally, in 2019 TP for traditional CE assessments (Figure 5A: 78%, 5C: 72%, 5E: 56%, and 5D: 39%) did not reflect the final exam TP of 90% (Figure 4I), but consistently *underpredicted* the final TP of the class. Whereas in 2020, TP consistently predicted pass rates of over 90% (Figures 5B: 96%, 5D: 95%, 5F: 93% and 5H: 92%), which endorsed the 99% final TP (Figure 5J). The variation and the magnitude of the TP of the various orthodox assessments during 2019 gave no predictive indication or extrapolation as to the final TP for the module. This is concerning, as low TP in pre-exam CA assessments is often used to flag modules for high failure and poor student performance. However, the TP across the CA online events were closely correlated to the final TP level of the module. Thus, TP from online assessment events appears to be a better proxy for predicting the final TP for the module.

Does gender provide an advantage in adapting to the digital teaching and assessment landscape?

Reports on the under-representation of the female gender in STEM fields have suggested that one gender may have an inherent advantage over the other or perhaps it is just an inherent preference that produces this statistical "elephant in the room"? This has been particularly evident in the computer sciences when comparing the number of female graduates to male graduates. As early as 2001 Cohoon reported that although access for women had improved dramatically over the years, this did not naturally translate into an improvement in the percentage of female graduates. This trend was similar in the engineering fields (Camp, 1997). This trend has persisted into recent times and Stoet and Geary (2018) reported on the "Gender-Equality Paradox" in STEM education. Their study suggests that in countries with more gender equality, there are fewer women in STEM. In America, just 17 percent of American computer science college degrees are awarded to women. Mahdy and Ewaida (2022) used a survey to investigate the perceptions of male and female students to transition from traditional studies to online studies. Here, they reported a trend that female students perceived that they were less comfortable with their technological skills during online learning of anatomy compared to male students, although this differential was not statistically significant.

We, therefore, wanted to use this opportunity to investigate whether a gender-based disparity existed in the medical sciences, especially when the presentation and assessment of the module were compelled to transition rapidly from the traditional (analog) teaching and assessment style to a digital format. Given the reported aversion of females to STEM, we hypothesized that the technological computer-based transition would pose more of a struggle for our female cohort of students.

We compared the performance of male students in Theory Test 1 and Theory Test 2 in 2019 (orthodox methods) with the comparative assessments in 2020. It is important to note that in the first term of 2020 orthodox methods were used to teach and assess, whereas in the second term the COVID-induced lockdown necessitated the migration to online systems (Figures 6A,B). In 2019, the distribution of male students' assessment marks reflected the distribution of the class, with the data showing a significant decrease (Figure 6A; $p < 0.003$) in the assessment performance in Theory Test 2. In 2020, the distribution once again reflected the performance of the whole class, where the distribution of the home-based online assessment was significantly (Figure 6B; $p < 0.0001$) increased. The female cohort of students also reflected the assessment distribution of the whole class both in 2019 (Figure 6C) and 2020 (Figure 6D). However, the 2019 decrease in the traditional assessment performance in Theory Test 2 was more pronounced in the female cohort of students, as indicated by the higher level of statistical significance (Figure 6C; Female TT2 (2019); $p < 0.0008$) compared to males (Figure 6A; TT2 (2019); $p < 0.003$). This implied that the female cohort of students in 2019 appeared to be slightly more challenged than the males in Theory Test 2. However, this differential did not occur in 2020, where the statistical significance between Theory Test 1 and Theory Test 2 both generated the same statistical p-value ($p < 0.0001$: Figures 6B,D).

This indicated that there was no gender differential in the way males and females responded to the challenge of online learning and assessment. This was confirmed by comparing the 2020 assessment data for male versus female cohorts of students for both Theory Test 1 and 2 (Figures 6E,F). Statistically, there was no assessment difference between the male and female student cohorts that reflects a differential in the way both genders adapted to the transition of an exclusive online platform. Our data was supported by the work of Zarcone and Saverino (2022) who also

compared the gender scores obtained both pre-and during the COVID pandemic. Their study also showed that both males and females responded equally to the challenge of transitioning to an online teaching format. Furthermore, collaborating our study, they showed that the average marks of both males and females improve with online teaching.

Summary remarks

Due to the continuing lockdown of countries and borders in an attempt to restrict the spreading of the COVID-19 virus, universities closed their doors, research laboratories, and students were sent home (Hedding et al., 2020). This led to a radical move away from face-to-face learning and teaching to investment in existing online platforms and exploration into the viability of the e-learning online environment as an alternative (Mishra et al., 2020; Rapanta et al., 2020). This most likely has implications for the long-term rendition of university courses, where we envision that online-based lectures and assessments will entrench themselves in the course offerings of most tertiary institutions.

Our in-depth investigation of the impact that the switch from face-to-face learning and sit-down assessments to online learning and assessments *via* the Sakai (iKamva) platform on the performance of a second-year Biomedical Science students indicates that online computer-based assessment is a promising alternative to traditional paper-based testing (Hosseini, 2017; Prisacari et al., 2017; Öz and Özturan, 2018). This transitional assessment ideology is supported by several reports of optimism for conducting assessments using online platforms (Wibowo et al., 2016; Martinavicius et al., 2017; Armoed, 2021). Reviews on grading and proctoring assessments during lockdown by Flaherty (2020) and García-Peñalvo et al. (2021) have noted the importance of e-proctoring in institutions that are adopting flexible multimodal solutions to computer-based assessment. Although digital scoring saves resources (Seale, 2002), some academics maintain that there is still a need to understand the impact, shortcomings, and learner proficiency (Guimarães, 2017).

Our TP data, gender assessment data and marks distribution data endorsed the view that second-year tertiary students are indeed ready to embrace online learning and teaching, together with online assessments.

The sudden transition to online studies amidst the trauma of the COVID-pandemic led to a concern as to whether students would be able to cope with the pressures of isolation and self-discipline on learning outcomes and assessments. However, in retrospect, students appeared resilient and appeared to cope well with the transition to online learning and home-based online assessments. We found that the gender data subsets correlate well with each other, where statistically there are no significant differences between the marks of gender subsets in terms of moving from paper-based to computer-based online testing platforms (Figures 5E,F). This indicated that the male and female cohorts of students were able to adjust to the challenges of the digital format of learning equally well. The data puts to rest the ideology that there is a gender differential in adjusting to learning and assessments in the online digital landscape.

Lastly, it was difficult to assign precise reasons for the improved online assessment performance. This could indeed have culminated from a combination of factors: Firstly, traditional lectures are not recorded and if students missed comprehending some components, or were just not as attentive during the lecture, they could easily miss an important part of sequential learning and would subsequently find it difficult to be able to make progress in comprehending foundational theoretical components of the theory, as opposed to online video-based lectures which were available on-demand, and in which you could easily backtrack over a section that you did not understand at the first opportunity. Secondly, the level of anxiety that is generated by orthodox assessments may indeed be counterproductive, compared to having a home-based online assessment. Further, the ability to have access to your notes during an assessment are not necessarily averse to facilitating in-depth learning, as the student has to engage the question and then intellectually engage with the course work. Our assessments were allotted a time allocation specifically to diminish the incentive to have to search Google or lecture PowerPoints to find answers and essentially reproduces an eproctoring phenomenon without the anxiety of literal proctoring (traditional assessment invigilation/supervision). As these assessments took place during strict lock-down conditions, during which no one was allowed to leave their homes, we can eliminate peer consultation during the assessments. Furthermore, we have confidence that the implementation of randomized questions and answers, in conjunction with the shortened timeframe to answer questions (< 1 min per MCQ), the limitation of online questions to only MCQs, played an important role in limiting the use of notes, or online resources during an assessment.

Limitations and strengths of the study

One of the limitations of this study is that the conditions of the COVID-induced lockdown, with its associated anxiety, fears, and physical constraints, would be difficult to repeat. Furthermore, the ethical constraints on proposing a similar study during "normal" tertiary conditions, would largely prevent the duplication of these assessment conditions. However, the data supports the postulate that students are resilient and have the necessary resolve to respond to these challenges, however *ad hoc* and difficult. One of the strengths of the paper is the statistical analysis and comparisons of the assessment data. Here we used Gaussian distribution curves to show that the traditional assessments were statistically identical to the home-based-online assessments in terms of the shape of the curve. This showed that the home-based-online assessments were able to categorize students in the same way as traditional supervised assessments, which provided much confidence that the standards of our assessments were maintained throughout the COVID-19 lockdown. This suggests that

home-based-online assessments are comparable to traditional assessments, provided that the assessment time constraints and randomization of questions and MCQ choices are implemented.

Conclusion

- Given the traumatic nature of the COVID-19 pandemic, students proved to be resilient in adapting to both online teaching and presentations, as well as to online assessments (Figures 3, 4).
- Online assessments move the assessment distribution curve to the right but did not affect the shape of the distribution curve: what this indicated was that weaker students still occupied the lower end of the distribution curve, while the majority of students were distributed centrally, leaving the above-average students occupying the right side of the distribution curve. This fundamentally suggested that assessment standards were maintained for the online assessments.
- TP for online CE assessment events is a better predictor for the final TP of the MBS231 module than traditional assessment TP (see Figure 4).
- Given that the kurtosis (shape) of the marks-distribution curve did not statistically differ between F2F and home-based online assessments, the higher marks for online assessments than for orthodox assessments (Figure 2) could be attributed to the online presentation of lectures and supporting materials and the decrease in anxiety being assessed at home.
- In the final analysis online exam TP was only marginally better than TP for orthodox lecture presentations and assessments (Online assessment TP: 99%; orthodox assessments: 90%).
- We found no gender-based difference or advantage between males and females in adjusting to online presentations and online assessments even though computer/technical skills are a definite advantage when navigating in an online paradigm (Figure 5).
- Our analysis was unable to conclusively differentiate whether the increase in online performance was due to students having *ad libitum* access to online video-based lectures or if it was due to the decrease in anxiety during the assessment, or indeed a combination of the two, and if access to learning material during the assessment contributed to the increase in assessment performance.
- Reflection: Better e-proctoring tools need to be further developed for home-based online assessments. However, the randomized generation of questions for every individual student, in parallel with time constraints to complete an assessment, and the strict government lockdown (South Africa: level 5), all compelled the students to engage the course content thoroughly before an assessment. We reasoned that there would be limited time to engage in online searches during the online assessment to ensure correct answers and still complete the assessment in the allotted time.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval were not required for the study on anonymized secondary data sets of human participants by the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements for anonymized secondary data sets.

Author contributions

DF compiled the manuscripts and wrote the results and discussion sections. DS editing the manuscripts and making sure we use correct educational terms, as DS is an educational specialist in Mathematics Department. KM cleaning the data, analyzing, and writing the methods section. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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The role of talent development on business performance in Islamic rural banks

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The objective of this study is to investigate talent development as a driver for strategic flexibility, digital readiness, and innovativeness and how these affect the business performance. This study used a quantitative approach using surveys from 391 managers and directors of Islamic rural banks in Indonesia, then the data were analyzed using structural equation modelling - partial least square (SEM-PLS). The results show that talent development has positive effects on innovativeness, strategic flexibility, and digital readiness. Moreover, strategic flexibility has positive mediating variables between digital readiness and innovativeness which also lead to business performance. This study provides contribution to the literature by integrating the digital readiness, strategic flexibility and innovativeness toward financial and non-financial performance. It also offers managerial implication that talent development drives those correlations.

KEYWORDS

talent development, strategic flexibility, business performance, digital readiness, innovativeness, Islamic rural banks

Introduction

The COVID-19 crisis has created a serious multi-dimensional disruption throughout the world, leaving the Islamic financial institutions in a state of instability due to high credit risk and systemic risk (Rizwan et al., 2020). Interestingly, this crisis also has accelerated the rapid adoption of digital transformation (Nachit and Belhcen, 2020). It is widely seen by the intense competition between Islamic rural banks and bank digital or fintech that provide new digital channels and products to gain strategic positioning in the digital age. Cloud computing and blockchain technology are employed by the competitors to improve their efficiency (Muia, 2017). The use of advanced digital technology triggered much discussion into its impact on talent development (TD). It is also still a debate among scholars whether TD could improve the performance of Islamic rural banks due to limited studies.

Theoretically, there are two views related to talent development, namely micro and macro. From a micro perspective, talent development can be defined as small initiatives aimed at people and organizations development. It consists of activities to support the

employee's learning and growth. Employees would understand their roles and responsibilities. From a macro perspective, talent development can be considered as an integrated HR function that is designed to attract, develop, motivate and retain employees. It encompasses the company's activities in recruiting the best candidates, retaining top talent, and developing leaders. This study is intent to fill the gap in the literature where majority of previous studies focused on talent development in Aziz et al. (2016).

From the empirical side, many companies are transforming their business structures, rapidly spending in new digital technology, experimenting with new possibilities in order to survive and compete with others (Farrington and Alizadeh, 2017; Nambisan et al., 2017). Numerous advanced technologies, such as Big Data, Artificial Intelligence (AI), Internet of Things (IoT), advanced manufacturing, robotics, and blockchain have been introduced to replace the traditional works in a new efficient way. Some scholars have documented talent development as a driver for strategic flexibility in Greek firms (Kafetzopoulos, 2022; Kafetzopoulos et al., 2022) and relate the strategic flexibility and business performance in emerging economies (Direction, n.d.; Yang et al., 2015; Xiao et al., 2021). Other academics link the firm's level of innovation and its degree of flexibility (Khin and Ho, 2018; Nassani and Aldakhil, 2021). However, there is a limited study that discusses the role of talent development for Islamic rural banks. Therefore, the objective of this study is to analyze the talent development as a driver for digital readiness, strategic flexibility, and innovativeness and its effect on business performance in Islamic rural banks.

This study gives contribution in three ways. First, majority of previous studies only investigate the individual relationship between strategic flexibility and innovativeness (Hewapathirana and Almasri, 2021; Kafetzopoulos, 2022), while this study develops a framework that integrates the correlation between strategic flexibility, digital readiness, and innovativeness which has not been exposed by previous studies. Second, this study offers a managerial perspective for Islamic rural banks in relation to talent development, while previous studies in this sector focused on financing quality (Rizky and Mongid, 2022) and customer satisfaction (Wibisono and Harto, 2018). Third, Islamic rural banks play an important role for MSMEs and other marginalized sectors that have difficulty to get financing from commercial banks. However, recent advancements in technologies have raised industry and academic attention to analyze its implementation in business. Thus, this study is intended to fill the gap between theory and practice. The finding provides a critical analysis for their readiness toward digital transformation and its effect on business performance.

This paper scrutinized into the following sections: first section presents the introduction, second section reviews the literature on Talent Development and Digital Transformation, third section describes the methodology, fourth section presents and discusses the results, practical implications, and concludes with conclusions and recommendations.

Literature review

Talent development

Talent development (TD) has been identified as an integral part in the overall talent management (TM) process (Cappelli, 2008). Baron (2011) defines talent development as a set of practices that are implemented by the organization to reap the benefits in the long term. It can also refer to how the organizations attract, select, develop and manage talent's skill in a strategic way (Scullion and Collings, 2011). Talent in this regard appears to be seen as an exemplary skill that people possess (Pruis, 2011). As explained by Gist et al. (1989), talent is a key in organizational success. Hamel (2009) suggests that developing talent skills results in a significant benefit to any organization (Charness et al., 1991).

Talent development is defined as an integrated process of planning, selecting, and carrying out talent development programs for all aspects of human resources (Garavan et al., 2012). Coaching, feedback, training, and mentoring are examples of processes in which Ibeh and Debrah (2011) characterized it as talent development. These processes are designed to elevate the talent's capacity at maximum level so that they have skills to fulfill organizational strategic goals, such as financial or performance objectives, or both (Hedayati Mehdiabadi and Li, 2016).

Dalal and Akdere (2018) identifies talent development as an effort to ensure that the firm has qualified talent to satisfy future demand and job changes, especially in this dynamic era of globalized and technology-driven world, exposing to no "talent shortage" within the firm. In light of this, Gandz (2006) argues firms often use talent development aimed to ensure planned succession and to strengthen their position as a talent magnet.

There are key roles who are in charge of reinforcing succession in organizational talent development, as conceptualized by Kaye (2011). Key responsibilities for talent development lie in the role of employee, the manager, and overall organization. The organization offers assets, tools, values, and culture in accordance with talent development practices. Managers play a role in assessing the needs in talent, clarify goals, support the development, provide feedback and monitor development. While employees or individuals set career goals, seek development opportunities, maintain motivation and implement development of the action plans.

Strategic flexibility

Strategic flexibility refers to the capacity of a firm to respond quickly to a rapidly uncertain and high volatility business environment (Hitt et al., 1998). Kristal et al. (2010) posits strategic flexibility as a combinative capability which enables firms to synthesize and utilize both current and newly obtained external knowledge in their operations. Viewed from the nature of capability, Eisenhardt and Martin (2000) argues strategic flexibility as dynamic and firm-specific because problem-solving

abilities are firmly embedded in and developed within firms. Teece et al. (1997) sum up that strategic flexibility is a dynamic characteristic that helps businesses to gain an edge in competitive markets.

The significance of a firm's strategic flexibility is found in its adaptability and responsiveness in addressing problems arising from fast-paced settings. Moreover, with strategic flexibility, firms are more receptive towards reallocating and reconfiguring their organizational resource, process, and strategy to deal with the problems (Zhao et al., 2010). A firm may require strategic flexibility to handle shifts in customer's preferences, competitive behavior, and other market factors (Chen et al., 2017). Strategic flexibility is also the key fundamental of firm resilience in dealing with crises, especially in COVID-19 crisis (Widiana and Soetjipto, 2021).

Innovations are more likely to occurred in a firm that values strategic flexibility. Being flexible allows firms to possess innovative ideas that are new to firms. This may benefit them in acquiring a competitive advantage, as innovations are the most important drivers. In their study, Nadkarni and Herrmann (2010) provides evidence that, by offering more adaptable processes and structures, it improves the firm's innovation performance in a hostile environment.

Innovativeness

Innovativeness is a key for a company's success as it represents openness in pursuit of a firm's competitive advantage (Miller and Friesen, 1982). Garcia and Calantone (2002) reveals innovativeness as a degree on which the firm possessed newness or advancement in products and services. The level of innovativeness influences the firm's existing resources, including capabilities, skills, and technology resources. Hence, in order to be innovative, firms must have a willingness to place emphasis on technology advancements, new offerings, enhanced product lines, and/or new services (Lumpkin and Dess, 1996).

Innovation is crucial to a firm's emerging survival strategy in the dynamic character of most marketplaces, where there is an intense rivalry among firms. In times of turbulent and unpredictive conditions, like crises, Ali (2021) conveys that a firm's innovativeness could aid firms to reduce the detrimental financial effects due to COVID-19, increasing their likelihood of survival. Reflecting an important means by which firms promote innovativeness, firms are likely employing an appropriate strategy through analysis of the external information (Dibrell et al., 2014).

The awareness about a firm's external environment may help firms in seizing opportunity, and enhancing its ability to transform its resource base to realign with the current changes (Kyrgidou and Spyropoulou, 2013). This encourages creative thinking behavior that can result in the invention of new products, services, or procedures (Dibrell et al., 2014). Research on technological and customer behavior trends, fulfillment of customer's needs, and new inventions of technology are several important inputs into the innovation process (Zahra et al., 2002).

Digital readiness

Digitalization has received tremendous attention from many practitioners and researchers in business management. Its existence has triggered a massive wave of technology transforming the overall global economy, business, and lifestyle (Moeini Gharagozloo et al., 2021). Matt et al. (2015), refers to this as a "digital transformation," which changed the tone across many sectors and businesses (World Bank Group, 2016). As technology continues to transform professional environments and modern workflows, the need for adopting technology for business sustainability becomes increasingly important (Mujiono, 2021).

Digital transformation is not about technology, rather it is about people, and, in particular, based on their ability to use digital technologies (Tabrizi et al., 2019). Digital transformation undertakes a process of organizational change which embeds emerging digital technology into the overall business operations (Gong and Ribiere, 2021). It is about how the business is switching the old way into the new way to create value and deliver benefits to customers. This process requires a major effort for the realignment of people, culture, and strategies of a firm to match with desired end stage.

Readiness is one of the steps necessary for a digital transformation to be successfully implemented (Welter, 2011). Readiness, as described theoretically by Weiner (2009) is a state of an individual being psychologically and behaviorally prepared to do something. Digital readiness refers to the level to which individuals in a firm perceive benefits of use and actual uses of digital transformation (Trischler and Li-ying, 2022). Fostering this digital readiness, in which individuals in a firm are willing to and capable of using such technologies, is key to successful digital transformation. Based on Nguyen (2022), a firm may foster a digital readiness through leveraging its human capital or development process.

Business performance

Business performance measures the success of a firm in achieving its goals. The success of a company in pursuing its goals can be viewed in two ways: financial and non-financial performance (Simon et al., 2015). Van Rompuy (2012) implies these two metrics are constructed based on the requirements and expectations of key parties involved in the company's strategy implementation. The overall performance of a firm is later compared to those of its top competitors (Tsai and Yang, 2013).

Two approaches measuring business performance were proposed by Kafetzopoulos et al. (2019). The first focuses on the outcomes, such as financial and market performance. The extent to which a firm achieves monetary results is considered as

financial performance (Hogan and Coote, 2014). It attempts to measure how well a business uses its assets and resources to generate revenue and how well it can pay off debts, showing the stability and health of a company. Market performance assesses the success of a firm's products and programs in existing businesses and in those related to its future positioning (Kandemir et al., 2006). Three separate dimensions of market performance are captured: sales growth, market share, and market development.

The second method for assessing business performance, based on Kafetzopoulos et al. (2019), relates to the variables that have indirect-effects on the outcomes, such as quality management, the firm's flexibility, resource use, and innovation level. These factors contend to have effects on how well the firm performs in terms of increasing firm value.

Development of Islamic rural banks in Indonesia

Over the past decades, Indonesia's Microfinance Institutions (MIs) industry has experienced significant growth. The number of MIs that received permits from the Financial Services Authority (OJK) increased by 149.42% annually on average between 2015 and 2019. There were about 223 MIs with a total asset value of IDR 1.13 trillion as of October 2020 (Otoritas Jasa Keuangan, 2020).

In their continued development, MIs are growing into Islamic Microfinance Institutions, emphasizing Shariah principles in their product or services offerings, where the concepts of riba (interest), maisir (gambling), and gharar (speculative trading) are prohibited. Four distinct discoveries in the Qur'an mention the ban of riba: Surah al-Rum (Chapter 30), verse 39; Surah al-Nisa (Chapter 39), verse 161; Surah al-Imran (Chapter 3), verses 130–2; and Surah al-Baqarah (Chapter 2), verses 275–81 (Aburime, 2008). Gross Financing of Shariah MI is recorded in the form of Mudharabah Financing, Musharaka Financing, and Murabahah Fincancing. Increased number of Muslims is one of the factors affecting the growth of Islamic MIs in Indonesia, which also raises awareness of Islamic finance (Aburime, 2008).

Islamic rural banks or Bank Pembiayaan Rakyat Syariah (BPRS) are included as Islamic Microfinance Institutions. According to successor Act No. 10 of 1998 concerning "Banking" which expressly positions BPRSs as a part of the national banking system adopting the Islamic philosophy (Khan et al., 2019). The business operations of BPRSs are governed by OJK regulation No. 3/POJK.03/2016 concerning "BPRS." Seen from their role, BPRSs strive to improve economic empowerment and society productivity by providing access to funds to low-income groups and Micro Small Medium Enterprises [MSMEs; Sakai, 2014; Law No. 1 (2013)]. BPRSs have a substantial effect on the country's economy, because 99% of Indonesian businesses are classified as MSMEs (Disli et al., 2022).

BPRS has grown robustly since its first establishment in 2009. This is reflected in the growth of 7% Year-on-Year (YoY), with total assets of IDR 12.36 trillion by the end of 2018 and estimated to reach IDR 20.69 trillion by the end of 2024. In 2022, assets grew 9.15% (YoY) from IDR 14.91 trillion to IDR 17.29 trillion (Otoritas Jasa Keuangan, 2022). In 2018, there were 160 Islamic rural banks in Indonesia; by 2021, there were approximately 163 Islamic rural banks, with BPRSs playing a larger role in their expansion (Otoritas Jasa Keuangan, 2021).

In the context of the financing disbursed by BPRSs, an upward trend was also evident. Murabahah Financing is the largest portion with a value of IDR 7.45 trillion in 2019, dramatically grew by 11% (YoY) on average per year from IDR 4.49 trillion in 2015. Musharaka Financing and Mudharabah Financing, respectively, took the second and third positions with a financing value of IDR 1.12 trillion and IDR 0.24 trillion in 2019. When compared to IDR 10.22 trillion in 2019, the total financing provided by BPRSs to MSMEs increased by 3.61% (YoY) or IDR 10.60 trillion in 2020 despite the COVID-19 pandemic. Overall, this sums up that the development of BPRS in Indonesia has great potential to grow.

Previous study

Based on the academic literature discussed above, several existing studies addressing the same issue can be seen from Table 1.

Hypothesis development

Digitalization helps companies in customizing products as per customer needs, changing business values and increasing focus to meet customer expectations for product quality and service standards (Xiu et al., 2017; Tsou and Chen, 2021). However, digitalization is also pushing people in organizations to change faster, which promotes the urgency for digital readiness (Tabrizi et al., 2019; Jun et al., 2021; Susanty et al., 2022). The help of talent development leads to the development of a lot of positive attitudes within the employee, such as an increase in motivation (Panda and Sahoo, 2015; Sheel and Nath, 2019). On the other hand, the acceleration of digital readiness is associated with attitudes of the employees (Nguyen, 2022; Trischler and Li-ying, 2022). Based on these arguments, the suggested hypothesis is:

> *H1:* Talent Development has a positive and significant impact toward Digital Readiness.

Strategic flexibility can be a source of competitive advantages as they possess their willingness to revise strategic plans based on their assessment of changing environmental conditions (Zhao et al., 2010; Vyas and Jain, 2021; Ruan and Mezei, 2022). The succession of talent development can be a source of such competitive advantage. In a hostile environment, learning and skills development are significant factors for talent-focused organisations to grasp the advantage of environmental opportunities (Dalal and Akdere, 2018; Bouranta et al., 2022). Armed with analysis and insights gained from the effective talent

TABLE 1 Previous study.

No.	Authors (Year)	Objective	Method	Result
1	Bouranta et al. (2022)	The aim of the paper is to determine whether leadership affects strategic flexibility and business performance taking into consideration the mediating role of talent management in these relationships.	- Exploratory interviews with managers from 462 Greek firms. - Partial Least Squared - Structural Equation Modeling (PLS-SEM).	- The results show that leadership drives firms to strategic flexibility and business performance, talent management fully mediates these relationships - Strategic flexibility also affects business performance positively.
2	Xiu et al. (2017)	The purpose of the paper is to examine the role of innovative HR practices as an important mechanism through which strategic flexibility affects firm performance as well as the role of gender-based leadership in this relationship.	- Questionnaires data from 598 small and medium-sized firms. - PLS - SEM	- There is a positive relationship between strategic flexibility and firm performance measured as employee productivity and the role of innovative HR practices as a mediator in these relationships. - Female leadership enhances strategic flexibility-performance relationship.
3	Khin and Ho (2018)	This study aims to examine the effect of digital orientation and digital capability on digital innovation, and also the mediating effect of digital innovation on the link between organizational performance and digital orientation as well as digital capability.	- Questionnaires data from 105 small to medium-sized IT firms in Malaysia. - PLS - SEM	- Digital orientation and digital capability have positive effects on digital innovation and also that digital innovation mediates the effect of technology orientation and digital capability on financial and non-financial performance.
4	Gouda and Tiwari (2021)	This aim of the paper is to investigate the impact of e-commerce capabilities on agricultural firms' performance gains through organizational agility.	- Questionnaires data from 280 managers of agricultural firms. - PLS - SEM	- Organizational agility plays a mediating role in conveying the positive influences of e-commerce capabilities on agricultural firms' performance gains.
5	Jun et al. (2021)	The purpose of the study is to investigate how digital platforms capability, improvisational capability and organizational readiness directly affect innovation performance.	- Questionnaires data from 647 managers of small and medium enterprises (SMEs) working in Pakistan. - PLS - SEM	- There is a significant and positive relationship of digital platforms capability, improvisational capability and organizational readiness with innovation performance. - Organizational readiness fully mediates the relationships between digital platforms capability and innovation performance.
6	Susanty et al. (2022)	The purpose of the study is to examine the effect of leadership style directly and indirectly through the mediation of employee readiness, innovation culture, technology capability and organizational structure.	- Questionnaires data from a telecommunications company in Indonesia with a total of 1,073 employees - PLS - SEM	- Adaptive leadership style has a direct and significant positive effect on the organizational agility level. - Employee readiness, innovation culture, technological capability and organizational structure function as mediators between adaptive leadership style and agility.
7	Adhiatma et al. (2022)	The purpose of the study is to develop a model of the relationship between SMEs' readiness to change, agile leadership and dynamic capability to implement a digital ecosystem for SMEs	- Questionnaires data from 250 creative SMEs in Semarang, Central Java, Indonesia. - PLS - SEM	- Three critical conditions for dealing with Industry 4.0: organizational readiness to change, agile leadership and dynamic capability.

(Continued)

TABLE 1 (Continued)

No.	Authors (Year)	Objective	Method	Result
8	Hameed et al. (2021)	The purpose of the study is to investigate the impact of business process reengineering on organizational performance in the Malaysian electronics manufacturing industry	- Questionnaires data from 103 samples electronics manufacturing companies listed in the Federation of Malaysia Manufacturers' directory. - PLS - SEM	- Business process reengineering dimensions (top management commitment, organizational readiness for change, information technology capabilities and people management) have significant positive impacts on organizational performance.
9	Chen et al. (2017)	The purpose of the study is to investigate the direct relationship between IT support for core competencies and strategic flexibility, and how strategic flexibility mediates the relationship between IT support for core competencies and firm performance	- Questionnaires data from IT and business executives in 148 Chinese manufacturing firms. - PLS – SEM	- IT support for core competencies has a positive influence on a firm's strategic flexibility, leading to superior firm performance.
10	Nassani and Aldakhil (2021)	The study's objective is to explore the impact of strategic orientation on the organizational innovativeness of SMEs. In addition, the study examines the intervening role of strategic alignment as well as the moderating role of strategic flexibility.	- Questionnaires data from 209 SMEs - PLS-SEM	- Strategic orientation is positively related to the innovativeness of SMEs. Strategic alignment links the gap between strategic orientation and innovativeness.

development process, firms can make more effective decisions about the types of resources to develop or acquire (Hedayati Mehdiabadi and Li, 2016; Prentice et al., 2020). Based on these arguments, the suggested hypothesis is:

> *H2:* Talent Development has a positive and significant impact toward Strategic Flexibility.

Innovativeness is a key towards sustainable growth of a firm (Jun et al., 2021). Barney (1991) has strongly argued that the competitive benefits which accrue to innovative firms are generated through unique capabilities which are difficult for competitors to imitate, are rare, and provide value. Innovativeness is conceptualized here mainly as cultural and behavioral aspects of the firm (Ferraresi et al., 2012; Nwankpa and Roumani., 2016; Papagiannidis et al., 2020). The roots of a firm's innovative capability may be derived from talent development processes. As employees' knowledge, skills and competencies are maximized and developed, they add value to the firm by possessing the capacity to yield innovative ideas, which may lead to new and improved products and services (Dibrell et al., 2014; Susanty et al., 2022). Based on these arguments, the suggested hypothesis is:

> *H3:* Talent Development has a positive and significant impact toward Innovativeness.

A large body of empirical research, summarized in Chen et al. (2017), Xiu et al. (2017), and Bouranta et al. (2022) strongly suggests that strategic flexibility improves a firm's performance. The presence of a strong, strategic flexibility enables firms to conduct frequent internal and external analyses, scan for emerging trends, and evaluate a number of strategy alternatives (Dibrell et al., 2014). Firms' ability to "act" or "react" as a result of their analyses have been shown to significantly influence their performance (Mithas et al., 2011; Noparumpa et al., 2021). Given this point, firms capable of concurrently acting and reacting are in a better competitive position than those that are unable, which makes them more superior (Xiu et al., 2017). Similarly, Bouranta et al. (2022) have exerted strategic flexibility as a valuable firm-specific resource that benefitted firms in terms of improved innovation performance, thereby potentially boosting customer' satisfaction. Based on these arguments, the suggested hypothesis is:

> *H4:* Strategic Flexibility has a positive and significant impact toward Business Performance.

Firms with the higher level of employee' digital readiness will enjoy more options among digital tools and are thus likely to attain a higher level of productivity (Jun et al., 2021). Digital readiness refers to a perception of the positive consequences that are caused by digitalization (Laurenza et al., 2018; Susanty et al., 2022). A greater digital readiness in a firm, increasing the likelihood of a firm to devote resources, such as financial resources, human resources, and R&D resources, to adopt digital technology (Moldabekova et al., 2021). Correspondingly, the adoption of digital technology in a firm plays an important role in creating competitive value if it is deployed in a way that leverages a firm's core competencies (Khin and Ho, 2018; Martínez-Caro et al., 2020). Further, in their study Chen et al. (2017), it is evident that embedding digital technology in core competencies can create competitive advantage for a firm and improve its

performance. Based on these arguments, the suggested hypothesis is:

> *H5:* Digital Readiness has a positive and significant impact toward Business Performance.

Success is increasingly a function of a firm's ability to develop and to deploy resources in an innovative way (Dibrell et al., 2014; Flannelly et al., 2014). Firms rely on innovativeness as a key value-enhancing activity, which transforms the benefits of innovation processes into increased financial performance (Susanty et al., 2022). Innovativeness allows firms to enhance their competitive posture through the development and delivery of innovative products and services (Hult et al., 2004; Dibrell et al., 2014). Firm's acceptance towards new ideas will result in economies of scale (continuously increasing efficiency and effectiveness of their operations) that have direct-effects towards both growth and financial performance (Yeniyurt et al., 2019; Gotteland et al., 2020). Accordingly, by emphasizing innovation, a firm can easily link their market, learning, and entrepreneurial orientations to business performance (Hult et al., 2004; Farrington and Alizadeh, 2017). Based on these arguments, the suggested hypothesis is:

> *H6:* Innovativeness has a positive and significant impact toward Business Performance.

Kafetzopoulos (2022) has confirmed that strategic flexibility is in association with innovativeness. The more innovative the firm is, the more it is associated with the complementary strategic plans capacity to respond and the flexibility of those plans. In other words, innovativeness is an action resulting from a strategic flexibility process. Further, there is a congruence between strategic flexibility and innovativeness (Alabbadi and Al-Masaeed, 2020). In Lokuge et al. (2019), strategic flexibility represented by the extent to which a firm may possess strong motivation to adapt to the external environment, is an important precursor to innovation. Digital readiness refers to attitudes and behaviors that underpin people's preparedness and comfort in using digital tools (Horrigan, 2016; Asokan et al., 2022). Firms possessing the capacity to implement adaptive strategies in response to an emergence of new technologies are likely to transform their workforce–combining features of knowledge, skill, and attitude of workforce–towards digitalisation, which causes the rate of readiness to increase (Alabbadi and Al-Masaeed, 2020; Fachrunnisa et al., 2020). Hence, digital readiness is fully correlated with the rate of flexibility of a firm. Thus, strategic flexibility processes and readiness are nearly equally positively associated with innovativeness. Based on these arguments, the suggested hypothesis is:

> *H7:* Digital Readiness has a positive and significant impact Strategic Flexibility.

> *H8:* Strategic Flexibility has a positive and significant impact Innovativeness.

Research methodology

Research design

In this study, the objective is to examine the impact of talent development toward digital readiness, strategic flexibility, innovativeness, and how these impact the business performance. Simultaneously, it investigates the mediating effect of strategic flexibility between digital readiness and innovativeness in Islamic rural banks. The present study used a quantitative research approach by utilizing primary data. Kowalczyk and Pounders (2016) defines quantitative research as a methodology which entails the use of numerical data measures to test the established hypothesis and interpret the results. Sugiyono (2013) applies this approach to survey or questionnaire data that are distributed to respondents.

Population and sampling

According to Sekaran and Bougie (2010), sampling begins with defining the research population. Sugiyono (2013) defines population as a generalization of territory that consists of items or subjects with certain characteristics chosen by the researcher to be examined and used to draw conclusions. The selected population is the internal stakeholders in Indonesian Islamic rural bank (Bank Pembiayaan Rakyat Syariah), while the sampling technique is convenience with the respondents hold position at least at the top management level, e.g., Chief Executive Officers (CEOs), Chief Financial Officers (CFOs), managers, etc.

The 10-times rule is widely used by the researchers in gauging sample size adequacy in SEM-PLS analyses (Wasko and Faraj, 2005; Van Raaij and Schepers, 2008). Incorporating the ten thumbs rule (10-times rule) proposed by Barclay and Smith (1995), the minimum required sample size is 250 respondents. The 10-times rule in SEM-PLS is made up of 10 times the number of predictors of: (1) the largest number of formative indicators used to measure one construct, (2) the largest number of structural paths directed at a particular latent construct in the structural model (Hair et al., 2021). This study received 420 data and removed 29 invalid data. Thus, the total sample in this study is 391 respondents.

Data collection

Partial Least Squares-structural equation modeling (PLS-SEM) was considered a key approach in this study (Hair et al., 2021). As can be seen from Table 2, a questionnaire survey instrument is distributed to the selected respondents *via* online form in order to collect the data in an acceptable amount of time. A questionnaire refers to a set of written formula questions (Sekaran and Bougie, 2010). Interval scales based on the Likert scale are frequently used to gauge a person's intention, attitudes, opinions, or perceptions regarding social phenomena (Joshi et al.,

TABLE 2 Measurement items.

Variables	Code	Items	Sources
Talent Development	TD1	The company's training and development programs designed to develop skills that benefit in completing my works effectively in the long-term	Hicks (2016), Fachrunnisa et al. (2020)
	TD2	The company's training and development programs has sharpened my characters to be more ethical, honest, and motivated	
	TD3	Information and Technology (IT) training program has helped me in leveraging the use of digital technology	
Strategic Flexibility	SF1	Within a specific timeframe, my company can create the products that customers demand	Dibrell et al. (2014)
	SF2	My company has an ability to adapt to technological advancements	
	SF3	My company has an ability to adapt to the needs of customers for its products and/or services	
Digital Readiness	DR1	Digital technology enables rapid responses and confirmation	Whitelaw et al. (2020)
	DR2	I believe digital technology offers flexibility and effectiveness	
	DR3	The adoption of digital technology in the workplace makes me feel at ease and helpful	
	DR4	I have the adequate digital technology facilities to support my works	
Innovativeness	IN1	My company is rapidly innovating new products and upgrading existing ones	Dibrell et al. (2014), Yıldız et al. (2014)
	IN2	My company impose policies for Research-and-Development (R&D) based on new technologies	
	IN3	My company has a capacity to identify innovative strategies to stay competitive	
	IN4	My company is investing in features & new banking product development to gain a competitive advantage	
Business Performance	BF1	My company can boost its profitability	Dibrell et al. (2014), Cabrilo and Dahms (2018)
	BF3	My company can improve the customer loyalty and satisfaction	
	BF3	My company can improve its brand image	
	BF4	My company can increase its capacity to penetrate new markets	

2015). In a Likert scale, the response takes the shape of a five-point scale. All variable measurements representing their own constructs were assessed by applying Likert scales. In this study, the researcher uses a scale range of 1–5 with each meaningful scale as follows: "1" Strongly Disagree, "2" Disagree, "3" Neutral, "4" Agree, and "5" Strongly Agree. SmartPLS 3 software was utilized for data analysis (Ringle et al., 2015).

Data analysis

In the current study, five variables have been used among which talent development, strategic flexibility, digital readiness, and innovativeness are considered as exogenous variables, while firm performance is a representative for endogenous variables. Descriptive statistics are used to measure the extent of agreement of the respondents for each of the items.

Five latent variables are examined to test the relationships between them using the PLS-SEM technique. PLS-SEM, which originated from Wold (1980), is a method to assess the causal relationships between endogenous and exogenous variables. PLS-SEM helps to assess the direct and indirect effects of coefficients of variables (Choo and Mokhtarian, 2007). There are two stages that must be completed to run PLS-SEM, (1) evaluation of the measurement model, and (2) evaluation of the structural model (Mehmetoglu and Venturini, 2021).

In the first stage, the measurement model must demonstrate construct reliability, construct validity, and absence of multicollinearity. Rho is used to measure the construct's reliability. Mehmetoglu and Venturini (2021) suggested that rho should be larger than 0.7 and less than 0.93. Meanwhile, the construct of validity can be seen in terms of convergent and discriminant reliability. Convergent and discriminant reliability can be used to describe the validity construct. While the discriminant validity is linked to the Fornell-Larcker criterion, the convergent validity is linked to indicator reliability (factor loadings) and Average Variance Extracted (AVE). The factor loadings are typically greater than 0.7, the AVE is usually at least 0.5, and the Fornell-Larcker criterion is expected to indicate that the AVE of the construct should be greater than its squared correlation (Mehmetoglu and Venturini, 2021).

In the second stage, the structural model must possess the coefficients of determination (R2), path coefficients, and multicollinearity. The fundamental suggestions for R2: small, moderate, and significant effects, respectively, are represented by values of 0.19, 0.33, and 0.67 (Mehmetoglu and Venturini,

2021). A statistically significant path coefficient (t-stat.) is one with a value greater than 1.96 or a value of p lower than 0.05 (Benitez et al., 2020). Multicollinearity was a problem that needed to be taken into account when assessing a structural model. In order to investigate this problem, the Variance Inflation Factors (VIF) values should be lower than 5 (Hair et al., 2014).

Results and discussion

Demographic respondents

Table 3 shows the demographic characteristics of the respondents. A total of 391 samples were received from the selected population. Based on the result, Male (71.4%) portion made up the majority of the samples out of the total respondents, compared to female (28.6%). More than 88% (88.46%) of the respondents reside in Java Island, the remaining samples are domiciled outside Java for about (11.54%). In terms of Work Experience, most of the respondents are having more than eleven years (>11 years) working experience (51.4%), followed by respondents with 9 to 11 years (20%), and 3–5 together with 6–8 years (11.4%), while the other respondents are having less than 2 years (5.7%). The obtained samples came from a range of educational backgrounds; the highest number of students earned Bachelor (62.9%), followed by Master (20%), while other remaining respondents earned Highshool Degree (8.6%), Vocational (5.7%), and Doctoral (2.9%). In terms of income level, majority of the respondents have a salary less than 10 million (48.5%), followed by between 10 million to 20 million (40%), while the lowest percentage was from a salary more than 20 million (11.5%).

Assessment of measurement model

The construct reliability and convergent validity for the measurement model assessment are presented in Table 4. The model shown in Figure 2 served as the foundation for the three measurements model. The figure shows the eighteen indicators (TD1, TD2, TD3, DR1, DR2, DR3, DR4, SF1, SF2, SF3, I1, I2, I3, I4, BF1, BF2, BF3, and BF4) are represented by five latent variables (Business performance; Digital readiness; Innovativeness; Strategic flexibility; Talent development).

Construct reliability

The correlation between latent and indicators is measured using Dillon-Goldstein's rho (DG rho). Table 4 shows all Dillon-Goldstein's rho values of the latent variables match the acceptance values (exceed the value 0.7 but lower than 0.93) (Business performance = 0.855; Digital readiness = 0.871; Innovativeness = 0.875; Strategic flexibility = 0.875; Talent development = 0.876), implying the construct's reliability was deemed satisfactory. Thus, demonstrating high internal consistencies as well as composite reliability.

Convergent validity

Average Variance Extracted (AVE) of each latent variable, which has a recommended threshold value of 0.5 and loading factors at least 0.7 served as a confirmation of the constructed model's validity.

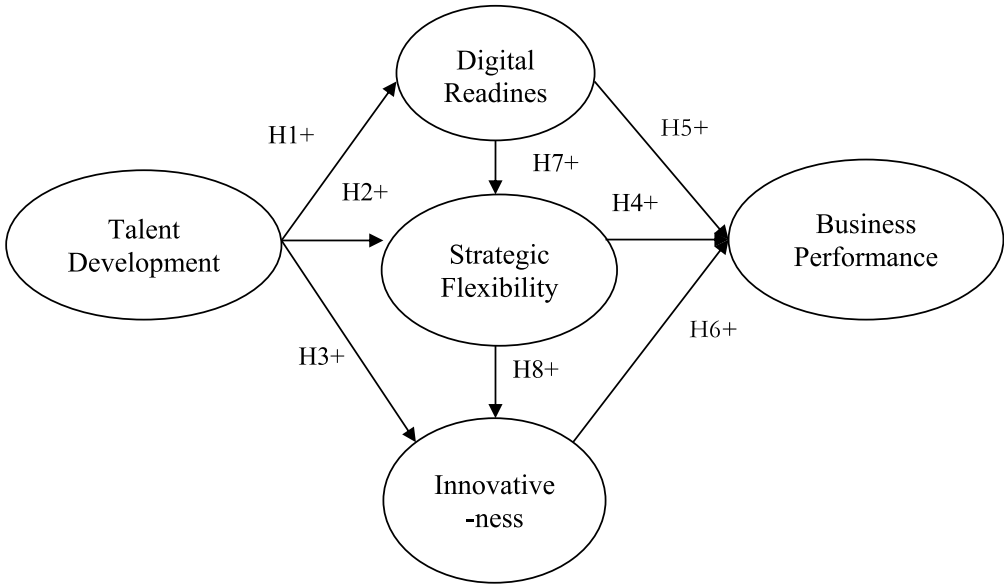

FIGURE 1
Conceptual framework.

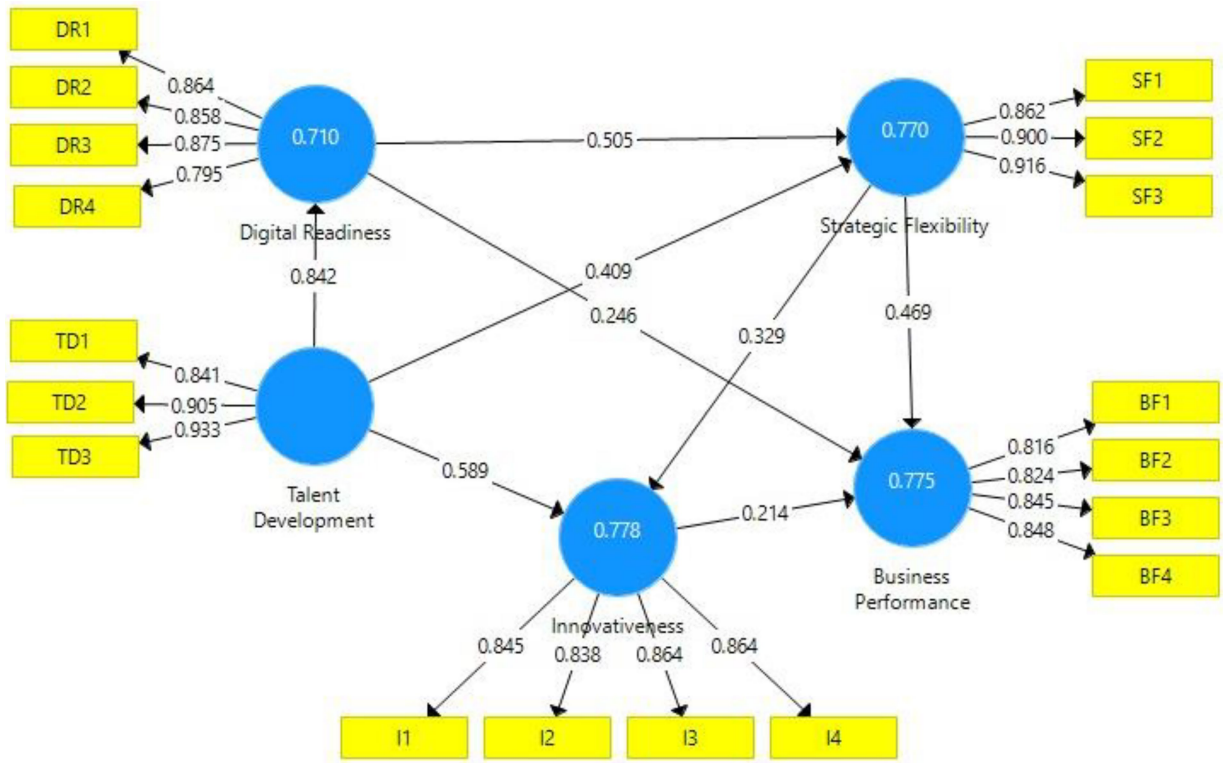

FIGURE 2
Outer loading.

Figure 2 and Table 4 show the values of loading factors all exceeded 0.7 and AVE with value at least demonstrating 5% significance level (Business performance = 0.694; Digital readiness = 0.720; Innovativeness = 0.727; Strategic flexibility = 0.797; Talent development = 0.799), suggesting all values correspond to the acceptable range. This exhibits the least errors captured in the construct.

Assessment of structural model

The structural model is evaluated after the performance of the measurement model has been assessed by looking at three quality systems of measurement: path coefficient, coefficient of determination, and multicollinearity. Tables 5, 6 present the measurement's results.

Path coefficient

Path coefficients evaluate the structural model's hypothesized relationships. It investigates the direct and indirect effects of predictor variables as well as the outcome. A good fit of path coefficient one with a value greater than 1.96 or a value of p lower than 0.05. Based on Table 5, it can be seen that all the coefficients range from 0.214 to 0.842 and are statistically significant with value of p lower than 5% of significance level. They also have a positive sign, which denotes a positive relationship, meaning that as a predictor rises, so does the outcome.

Coefficient of determination (R^2)

R-squared (R^2) is the measurement of "goodness of fit." It quantifies the variation in the outcome explained by a group of predictor variables. Based on Table 6, the result of R^2 values of all variables are showing large effects, as it appears to exceed 0.67 in the rule of thumb (Business performance = 0.775; Digital readiness = 0.710; Innovativeness = 0.778; Strategic flexibility = 0.770).

Multicollinearity

The absence of multicollinearity among variables is one of the fundamental tenets in structural measurements. Multicollinearity refers to any confounding effects as a result of highly correlated variables, and is assessed using the Variance Inflation Factor (VIF). Hair et al. (2014) suggests limiting the VIF values to less than 5. Based on Appendix Table A1, the findings demonstrate that there is no discernible multicollinearity among the variables used because all VIF values are below 2.5.

Hypothesis testing

Based on Appendix Table A2, talent development is found to have a positive impact on digital readiness where value of p is less than alpha value ($0.000 < 0.05$). Thus, we accept the first hypothesis. Talent development is found to have a positive impact on strategic flexibility where value of p is less than alpha value

TABLE 3 Demographic respondent.

Demographic Variables		Frequency	Percentage
Gender	Male	279	71.4%
	Female	112	28.6%
Domicile	Java Island	346	88.46%
	Outside Java Island	45	11.54%
Work experience	0–2 Years	24	5.7%
	3–5 Years	44	11.4%
	6–8 Years	44	11.4%
	9–11 Years	78	20%
	>11 Years	201	51.4%
Educational background	High School Certificate	37	8.6%
	Vocational Certificate	22	5.7%
	Bachelor Certificate	246	62.9%
	Master Certificate	78	20%
	Doctoral Certificate	8	2.9%
Income level	Rp 0 - Rp 10,000,000	190	48.5%
	Rp 10,000,001 - Rp 20,000,000	156	40%
	> Rp 20,000,001	45	11.5%

TABLE 4 Assessment of construct reliability and convergent validity.

Variable	Cronbach's alpha	rho_A	Composite reliability	AVE
Business performance	0.853	0.855	0.901	0.694
Digital readiness	0.87	0.871	0.911	0.72
Innovativeness	0.875	0.875	0.914	0.727
Strategic flexibility	0.873	0.875	0.922	0.797
Talent development	0.873	0.876	0.922	0.799

(0.000 < 0.05). Thus, we accept the second hypothesis. It also found that talent development has a positive impact on innovativeness where value of p is less than alpha value (0.000 < 0.05). Thus, we accept the third hypothesis.

In mediating variables, strategic flexibility is found to have significant and positive impact toward business performance where value of p is less than alpha value (0.000 < 0.05). Digital readiness is found to have significant and positive impact toward business performance where value of p is less than alpha value (0.001 < 0.05). Moreover, Innovativeness is also found to have significant and positive impact toward business performance where value of p is less than alpha value (0.003 < 0.05).

In addition, digital readiness is found to have significant and positive impact toward strategic flexibility where value of p is less than alpha value (0.000 < 0.05) and strategic flexibility is found to have significant and positive impact toward innovativeness where value of p is less than alpha value (0.000 < 0.05).

Discussion

Previous studies have discussed the relationship between talent development and business performance. Gathungu and Mwangi (2012) viewed talent development as an important role for performance. Talent development is a new contribution to existing talent management practices, not a replacement. An addition that makes the link between talent management and strategy (even) more explicit and can assist organizations in taking the next step toward realizing their ambitions through targeted deployment and development of top talent in key positions (Schreuder and Noorman, 2019).

The study shows that talent development positively and significantly affects digital readiness. Talent development programs provide benefits for the individual, for example it assists them to create more strategic solutions, provide a platform to improve their skills and increase work motivation. In the digital era, numerous advanced technologies, such as Big Data, Artificial Intelligence (AI), Internet of Things (IoT), advanced and blockchain have been introduced to replace the traditional works in a new efficient way. Many companies are transforming their business structures, rapidly spending in new digital technology, experimenting with new possibilities in order to survive and compete with others (Farrington and Alizadeh, 2017; Nambisan et al., 2017). The company's training and development programs, in particular digital literacy, are designed to develop the employee's skills in using new technologies and provide them with a good ability to accept new challenges.

Talent development also shows a positive and significant impact on strategic flexibility where the individual and organization have an ability to adapt with new changes, in particular during technological advancement. Training and development programs developed by islamic rural banks together with the support from government programs, improve the ability of companies to respond to the customer demand. This finding is in-line with the previous study conducted by Kafetzopoulos (2022) that talent development positively and significantly affects the managers in Greek firms to be more flexible in its strategy. In addition to that, talent development also plays an important role in the Islamic rural banks which trigger them to be more innovative in producing more competitive products. Training and development programs also encourage them to identify better innovative strategies to stay competitive.

Digital readiness is found to have significant and positive impact on business performance of Islamic rural banks. Wade and Shan (2020) defined digital transformation as the integration and deployment of digital technology which fundamentally alters their

TABLE 5 Path coefficients.

Variable	Business performance	Digital readiness	Innovativeness	Strategic flexibility	Talent development
Business performance					
Digital readiness	0.246			0.505	
Innovativeness	0.214				
Strategic flexibility	0.469		0.329		
Talent development		0.842	0.589	0.409	

TABLE 6 Hypothesis testing.

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	*P* Values	Result
TD→DR	0.842	0.840	0.027	31.354	0.000	H1 Accepted
TD→SF	0.409	0.406	0.071	5.744	0.000	H2 Accepted
TD→I	0.589	0.592	0.084	6.976	0.000	H3 Accepted
SF→BP	0.469	0.465	0.085	5.549	0.000	H4 Accepted
DR→BP	0.246	0.253	0.076	3.246	0.001	H5 Accepted
I→BP	0.214	0.211	0.071	3.029	0.003	H6 Accepted
DR→SF	0.505	0.507	0.064	7.841	0.000	H7 Accepted
SF→I	0.329	0.326	0.081	4.082	0.000	H8 Accepted

business model. Many industries have benefited from integrated, shared, and updated real-time mobility systems both personally and professionally (Dwivedi et al., 2021). The inclusion of smart-based technologies leads to shifting in people's behavior, for example, the adoption of remote working, distance learning, and cashless society (Piccinini et al., 2015). The adoption of new advanced digital technologies must be followed by preparedness of the people. Firms with higher degree of employee' digital readiness will result in greater productivity, thus likely to attain improved firm performance (Jun et al., 2021; Moldabekova et al., 2021).

In addition, strategic flexibility is also found to have significant and positive impact on Islamic rural bank's performance. This finding is in-line with previous studies that analysed the relationship between strategic flexibility on business performance (Cingöz and Akdoğan, 2013). In this study, digital readiness drives the strategic flexibility and innovativeness. Digital technologies have paved the way for developing innovative Shari'ah compliant products, which strengthen the competitive advantage of Islamic financial sector (Hasan et al., 2020).

Conclusion, limitation and recommendation

Conclusion

This study is aimed to investigate the impact of talent development toward digital readiness, strategic flexibility, innovativeness, and how these impact the business performance. Simultaneously, it investigates the mediating effect of strategic flexibility between digital readiness and innovativeness. According to the result, talent development significantly affects digital readiness, strategic flexibility, and innovativeness. Those variables also significantly affect the business performance. Furthermore, digital readiness significantly affects the company to be more flexible in developing their strategy, which also leads to more innovativeness. Overall, the proposed model explained 77.5% of the variance that can predict and explain the drivers of business performance in Islamic rural banks.

From the theoretical perspective, this study expands the literature of talent development where it provides a new framework that digital readiness, strategic flexibility, and innovativeness could lead to the business performance. By looking into the digital transformation in business processes, it has a significant impact on the structure of organizations, including their goals and identities (Holmström, 2022). On the other side, it also creates opportunities for information technology security threats such as cyber-attacks in the form of intrusion into organization's existing information technology through the distribution of malware, viruses, ransomware, and spam on users' emails, resulting in the attempted theft of sensitive data. Upgrading employees' skills in digital training courses strengthen organizations' defenses to protect company assets and information, increases employee discipline to comply with security regulations, reduces the risk of cyber-attacks, and increase customer satisfaction and trust. Thus, this study also assists future researchers in better understanding the relationship between cyber security readiness, technology readiness, and performance.

From the managerial perspective, this study can be used as a reference for Islamic rural banks to fully integrate its talent development strategy with digital transformation. Digital technology will create powerful banking and financial institutions

to completely reimagine how they operate, launch groundbreaking products and services, and, most importantly, reduce customer experience disruptions. One of the digital technology, Artificial intelligence (AI), has been used by this industry for customer identification and authentication. It helps the organization to enhance customer experiences and improve middle office function. In addition to AI, the existence of robotic process automation (RPA) and augmented reality also provide numerous benefits to businesses, such as improve customer experience and employee productivity, save money, time, and reduces the manual process.

However, many companies are facing increasing pressure to make digital investment as a strategic priority and to transform these investments into innovative business processes, new products, and business models. Digital investment, which refers to a firm's strategic technology investment in order to investigate how cutting-edge digital technologies may potentially differentiate the firm's business, transactions, and operations, is viewed as a critical imperative for firms seeking to remain competitive and maintain market positions. The success implementation of digital technology is not solely based on the investment, but also skills and competencies. It proved that the training and development program could improve the ability of an individual and organization to adapt with new changes in digital disruption and market conditions. Therefore, the manager and directors of Islamic rural banks develop organizational structure and boost the innovative culture.

Limitation and recommendation

For future research, there are several possible considerations: (1) the number of respondents is small compared to the total numbers of employees at Islamic rural banks in Indonesia. Thus, this study encouraged further research to expand the sample size that covers at least 80% of the population; (2) this research does not differentiate staff based on their unit/departments. Perhaps it is beneficial to include the adoption level of the digital readiness between different units to enrich the discussion; (3) the study only focused on strategic flexibility, digital readiness, and innovativeness as mediators. Further studies could expand the model by examining the perceptions of employee through several digital talent programs and compare these with employee performance; (4) the research model can be extended to the antecedents to predict digital readiness, such as organizational culture of using technologies.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

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

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Appendix

TABLE A1 Coefficient of determination.

Variable	*R* square	*R* square adjusted
Business Performance	0.775	0.773
Digital Readiness	0.71	0.709
Innovativeness	0.778	0.777
Strategic Flexibility	0.77	0.769

TABLE A2 Multicollinearity.

	BF1	BF2	BF3	BF4	DR1	DR2	DR3	DR4	I1	I2	I3	I4	SF1	SF2	SF3	TD1	TD2	TD3
VIF	2.4	2	2.5	2.2	2.2	2.3	2.6	1.7	2.1	2	2.3	2.3	2	2.5	2.8	1.8	3.2	3.7
	21	98	89	26	49	84	74	40	95	47	21	48	1	61	1	2	57	20

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Student evaluation of teacher digitals skills at Granada University

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The following study is a descriptive/correlational analysis of students' perception of digital competence in teaching. It is based on the current needs of university students with regard to the digitization of teaching and learning processes. Knowing student satisfaction with teaching digital skills could be used to propose improvements in the quality of university education to the extent that it can channel the various socio-economic demands. The European Higher Education Area is not oblivious to this problem by creating a framework of ambitious objectives for member states where ICT and digital competence of teachers are a priority. The research is carried out at the University of Granada and takes as a reference the framework: Marco Común de Competencia Digital Docente. This Framework in the context of Spain is concerned with indicating which areas educators need to acquire a skill higher degree differentiating between the following levels of classification: basic, intermediate and advanced. A quantitative correlational study was carried out, and an online questionnaire/form was distributed to a random probability sample of 307 students at the University of Granada belonging to different faculties of education. According to the results obtained, the students unanimously share the opinion that, the lecturers at Granada University do not possess a sufficient level of experience or training to competently deliver course content in a purely digital format.

KEYWORDS

Higher Education, teacher evaluation, teacher skills, educational technology, student evaluation of teacher performance

Introduction

Society and technology have advanced to what we know today as the information society. In Gisbert Cervera et al. (2016) already warned about how social differences are becoming more evident and that it is affecting every aspect of society, including the education. It is important to develop digital skill as it has become essential in order to survive and even in modern society it could be claimed as a right (Alonso-García et al., 2018).

This information society where the Information and Communication Technologies (ICT) are so essential, people could be divided in to two categories: digital immigrants and digital natives (Aguilar-Salinas et al., 2019). Young people who were born and grew up in this society often have studied with ICT and new technological innovations in their environment. The modern technological culture and digital proficiency of the average student is radically different when compared to the environment that the current generation of educators grew up in. This creates a gap in knowledge and ability, between student and teacher, in many situations regarding the use of technological systems (Romero-Rodríguez et al., 2020).

Due to that, the methodological lines must include ICT and give the students an opportunity to have a more learning by doing perspective in education (Han and Ellis, 2020). However, to achieve that goal with efficiency one of the most important factors is the digital skills of the teacher (Moreno-Guerrero et al., 2020).

Digital skills could be defined as the level of ICT group of knowledge's, including but not limited to, technological, informational, multimedia, and creative communication. Learning skills from all groups of knowledge is called the ICT literacy (Fuentes et al., 2019).

Otherwise, the concept of digital skills could be divided in three areas, technical, methodological and social categories. Technical skill could be defined as knowledge about a field and being able to manage the information related to that area of study. Methodological skills are about applying the knowledge and finally, social skills using ICT focus on using them with an ethical meaning and participate on the social activities (Trujillo et al., 2020).

Digital skills involve the critical and safe use of Information Society Technologies for work, leisure and communication. Relying on basic ICT skills: "use of computers to retrieve, evaluate, store, produce, present and exchange information, and to communicate and participate in collaborative networks via the Internet." (European Parliament and the Council, 2006).

Moreover, at the same year the European Parliament acknowledged the fact that educators need an adequate level of training in ICT by publishing the following statement.

Following this statement Durán Cuartero et al. (2019) advised that European Higher Education Area recognize ICT as an exigency and a main source of information. They argued that universities and their professors have to evolve, innovate and reinvent themselves to adapt to the information society. During the education of the next generation of teachers and professors it is essential to break educational barriers and give new meanings to the teaching process to meet student's needs (Alonso-García et al., 2018). Based on that, new methodologies are being developed such as, mobile learning, blended learning or flipped classrooms to name a few. The development of these methodologies can be greatly attributed to ICT and the resources it provides (Alonso-García et al., 2019). The use of those methodologies comes with the possibility of the permanent education, collaborative and the auto regulation of the student as the adaptation to different schedules (Romero-Rodríguez et al., 2020).

In Spain the main institution that coordinates educators knowledge regarding ICT is the "Instituto Nacional de Tecnologías Educativas y de Formación del Profesorado (INTEF)" which in 2017 developed the "Marco Común de Competencia Digital Docente" which is a reference paper that divides digital skills into five areas:

(1) Information and informational knowledge. This area focuses on an educator's ability to find, verify and retain information from digital services.
(2) Communication and collaboration: This refers to the ability to share different types of files and cooperate in different contexts using ITC.
(3) Digital media creation: The creation of new documentation and the updating of already published content, in order to ensure all available documentation is factually correct based on the latest research.
(4) Security: The ability to protect the digital devices and surf online with no risk.
(5) Problem solving: The ability to use, and in what manor to use, ICT when approaching a problem. In some situations, this includes the exclusion of ICT when trying to resolve a problem.

Furthermore the COVID-19 situation has changed every aspects of educator's lives. During the mandated period of lockdown in different areas around the world, educators had to quickly adapt their methods of delivering content to students. Scientific literature in recent years has focus on developing new teaching techniques using different digital devices (Agencia Estatal Boletín Oficial del Estado, 2022). As a result of this a new paper was published in Spain titled: resolución de 4 de mayo de 2022, de la Dirección General de Evaluación y Cooperación Territorial, por la que se publica el Acuerdo de la Conferencia Sectorial de Educación, sobre la actualización del marco de referencia de la competencia digital docente which became the new framework paper. The new framework is similar to the previous one as it grades educators from an A1 to C2 level however the areas of evaluation have changed to:

(1) Professional Commitment.
(2) Digital Media.
(3) Teaching-Learning process.
(4) Evaluation and feedback.
(5) Students' empowerment.
(6) Development of students' digital skills.

On 14 March 2020, Royal Decree 463/2020 was approved in Spain, declaring a state of alarm for the management of the health crisis situation caused by COVID-19. Traditional classes were banned and were later moved to online, with

the new vaccination mandate, the possibility of face-to-face classes began to change. From 17 September 2020, at the start of the 20/21 academic year, the University of Granada opted for semi-attendance with classes taught both face-to-face and online.

This new educational reality has brought about the necessary transformations for the digital era. Evaluation methods, curricular maps and teaching guides must be adapted for active student learning and formative assessment (Mora-Cantallops et al., 2022). To overcome the physical barrier, virtual learning communities have been created to facilitate fluid communication between participants. In addition, the active learning that requires ICT as the main tool also helps students create their own learning process using ICT and as they do, they start developing their digital skills (Aguilar-Salinas et al., 2019).

According to García-Planas and Taberna Torres (2020), the adaptation from a totally face-to-face model to an online or blended model has been very quick. Far from perceiving that the change has had a negative impact, they argue that they have been able to discover and explore issues that were not even considered before online or blended learning became the new norm. The most relevant example is the reduction of theoretical content which is accompanied by a series of activities allowing students to go deeper on the knowledge they get and have time to assimilate it appropriately. In this way, the contents and skills acquired during the lockdown contribute to their updating for the social perspective and working scenario where ITC are essentials (Torrado Cespón, 2021).

During the lockdown, many studies have been published on the assessment of teachers' digital skills (Mannila, 2018; Fuentes et al., 2019; Ruiz Ruiz, 2020). These investigations have detected different strengths and weaknesses of educators from the perspective of students and educators themselves (Mora-Cantallops et al., 2022). The types of evaluations most frequently carried out are perceptual and performance evaluations (Rodríguez-García et al., 2019; Recio Muñoz et al., 2020; Mora-Cantallops et al., 2022).

In this context, evaluations of teaching performance are necessary and provide significant information, as they show how, in this period, ICT in particular has been a useful tool for the teaching/learning process. Also, they show how teacher training in digital skills is still an aspect that needs to be improved, so that the performance of education through digital tools can be efficient. Thus, Han and Ellis (2020) show that blended learning may not be beneficial if it is not accompanied by teacher training follow-up on the correct implementation of this learning approach, showing how teacher training is a decisive factor in the implementation of ICT and active methodologies.

Likewise, another challenge is the educators' perception of blended or virtual education, as in many cases it is not positive (Aguilar-Salinas et al., 2019). They are unaware, for example, of the possibilities of open educational resources (Mora-Cantallops et al., 2022). Along the same lines, Romero-Rodríguez et al. (2020) show that although mobile devices are a commonly used tool among university students, they have not been integrated into the classroom.

On the other hand, Mora-Cantallops et al. (2022) point out that Spanish university teachers generally perceive themselves to have a level of digital competence between B1 and B2. This data varies according to their area of knowledge among other variables such as gender and age. For example, in their study, teachers in the areas of social sciences and humanities show a better self-perception than those in health sciences. Similarly, Boring (2017) reports more positive evaluations of male teachers by students regardless of their gender than those of female teachers. Tangalakis et al. (2022) however, in their evaluation results do not obtain such a significant differentiation, although they perceive less respectful attitudes toward their female teachers in distance education by male students.

The aim of this study is to find out the perception of students at the University of Granada on the digital skills of teaching staff based on the Marco Común de Competencia Digital Docente (Instituto Nacional de Tecnologías Educativas y de Formación del Profesorado [INTEF], 2017). The following questions will be addressed: Do male and female students have the same perception of the digital competences of their teachers? Are there differences between the digital competences of the teaching staff according to the students' branch of knowledge? Does the assessment of the teacher vary according to the self-perceived digital competence of the student?

Materials and methods

In this descriptive and correlational analysis study, the level of digital skills of teachers is assessed based on students' perceptions. Thus, the aforementioned research questions have led to the following hypotheses:

> H1: There are statistically significant differences between students' gender and the perceived level of digital competence of their teachers.

> H2: There is a correlation between students' age and their perceived level of digital competence of their teachers.

> H3: There is an association between students' branch of knowledge and the perceived level of digital competence of their teachers.

> H4: There is a correlation between the mode of course attendance and the perceived level of their teachers.

> H5: There is a correlation between students' self-perceived level of digital competence and the perceived level of their teachers.

Participants

The population of this research is made up of students that attended the University of Granada in the year 2021. For the composition of the sample a non-probabilistic sampling was used. Specifically, the questionnaire was addressed to the entire population by means of an invitation email, using the institution's database. A total of 307 students responded from May to December 2021. The proportions of participants in relation to subject areas are as follows: 110 students (35.8%) from Social Sciences, 65 (21.2%) from Arts and Humanities, 57 (18.6%) from Health Sciences, 38 (12.4%) from Sciences and 37 (12.1%) from Engineering and Architecture.

Instrument

The research technique used is the survey; therefore, an online questionnaire was designed as an instrument with the support of the Google Forms tool. The questionnaire was composed of 28 items distributed in 7 sections. The first section contains 5 questions about the socio-demographic data of the students (gender, age, nationality, field of knowledge and attendance); the second section contains 2 questions related to the digital skills of the students (certification and self-perceived level of digital competence); and the last five sections contain 21 questions in total, with a Likert-type scale, which are directly associated with the level of digital skills that the students perceive about their teachers. For this purpose, the five competence areas established by the Marco Común de Competencia Digital Docente (Instituto Nacional de Tecnologías Educativas y de Formación del Profesorado [INTEF], 2017) were taken as a theoretical basis; these areas are: (1) Information and information literacy, which contains 3 competences; (2) Communication and collaboration, 6 competences; (3) Creation of digital content, 4 competences; (4) Security, 4 competences; and (5) Problem solving, 4 competences. Each of the 21 competences is measured at 6 progressive competence levels: A1 and A2—basic level, B1 and B2—intermediate level, and C1 and C2—advanced level.

The validation of the instrument was developed through the process of expert judgment, with the participation of 10 professionals in the field of Didactics and School Organization from Spanish and foreign universities. Additionally, the internal consistency of the instrument was calculated through the omega coefficient for each of the five competency areas; in all cases $\omega > 0.80$ and an average $\omega = 0.92$ was obtained. According to Deng and Chan (2017) and Viladrich et al. (2017), the omega coefficient is appropriate for research in which a Liker-type scale has been used; and according to Dunn et al. (2014), in these cases, this coefficient indicates less risk of underestimating or overestimating reliability with respect to Cronbach's alpha.

Data analysis

Once the online questionnaire was closed, the data were entered into the SPSS statistical program and a descriptive statistical analysis of frequencies was applied, with the purpose of identifying the socio-demographic profile of the students who responded to the survey. Subsequently, in order to resolve the hypotheses, a series of analyses were carried out using several statistical tests that are explained later in the results; among them: Mann-Whitney U, Pearson's correlation, Kruskal–Wallis H, Chi-square and Kendall's tau correlation.

To do this, the level of digital skills per competence area was previously rated from 1 to 6; in such a way that a set of 6 values was obtained, one for each of the five skills areas and finally one that rates the five areas as a whole. To create each of the 6 values, the average of the perceived levels was calculated [$NP = \Sigma(x1,x2.xn)/n$]; where NP = Perceived level, x = digital skills and n = number of digital skills.

Results

Socio-demographic student's profile

Of the 307 students who participated in this research, 214 (69.70%) identified with the female gender, 89 (29%) with the male gender, and 4 (1.30%) with the non-binary gender. They range from 18 to 59 years of age; the average age is 21.95; the median is 21; and the mode is 20. The majority are Spanish, i.e., 292 (95.10%); 3 (1.00%) are Venezuelan; 2 (0.70%) are Italian and 2 (0.70%) are Moroccan; and there are only 1 (0.30%) Armenian, Belgian, Cypriot, Ecuadorian, Greek, Iranian, Italian-Argentinean and Romanian student.

According to branches of knowledge, 110 (35.80%) are students of Social and Legal Sciences, 65 (21.20%) of Arts and Humanities, 57 (18.60%) of Health Sciences, 38 (12.40%) of Sciences, and 37 (12.10%) of Engineering and Architecture.

Regarding the mode of class attendance, 131 (42.70%) had blended attendance, 121 (39.40%) mixed, 51 (16.60%) virtual, and 4 (1.30%) face-to-face.

Evaluation of the area of information and information knowledge

Considering the students' evaluation of the different areas of competences depending on the sample, the evaluation is negative. For example, the branch of Information and Information Knowledge stands out for most students concentrated at an intermediate level with a total student representation of 48.96% between levels B1 and B2. After the intermediate level, the level with the highest percentage is the basic level with 9.01% for level A1 and 18.24% for level A2. The remaining 23.78% is divided between C1 (17.05%) and C2 (6.73%) (Table 1).

TABLE 1 Evaluation of the area of information and information knowledge.

Level	Percentage
A1	9.01
A2	18.24
B1	24.10
B2	24.86
C1	17.04
C2	6.73
Total	100

TABLE 2 Evaluation of communication and collaboration area.

Level	Percentage
A1	13.30
A2	20.41
B1	23.45
B2	21.44
C1	14.82
C2	6.56
Total	100

TABLE 3 Evaluation of content creation area.

Level	Percentage
A1	18.40
A2	21.58
B1	20.60
B2	17.67
C1	12.70
C2	9.04
Total	100

Evaluation of the area of communication and collaboration

Student evaluation in the area of Communication and collaboration is similar to that of the previous competence. Once again, the intermediate level (B1 and B2) has the highest percentage with 44.89%. However, in this competence, when compared to the previous one, there is a higher percentage of the sample who considers their teaching staff to have a basic level. The A2 level standing out with 20.41% and A1 level with 13.30%. The percentage of the sample who considers their teachers to have an advanced level, which is the optimum one, is 21.39% (Table 2).

Evaluation of the area content creation

The area of digital content creation is one of the worst rated according to the sample. In this area, the basic level is the one with the highest percentage. The basic level has 18.4% for level A1 and 21.58% for level A2. The intermediate level, although not the one with the highest percentage, is the second one with 20.6% at B1 level and 17.67% at B2 level. These percentages decline for the advanced level with 12.7% for level C1 and 9.04% for level C2 (Table 3).

Evaluation of the area of security

The analysis of this area is similar from the rest. The majority of the answers are in the medium level (B1 and B2). The percentage of this level is 43.73%. Following this level highlight the basic level with 36.32%. Finally, the higher level only has the 19.95% been the lowest percentage in this area (Table 4).

Evaluation of the area of problem solving

Problem solving is the lowest rated area in this study. Of all the competence areas, the area of digital content creation

TABLE 4 Evaluation of the area of security.

Level	Percentage
A1	15.55
A2	20.77
B1	24.35
B2	19.38
C1	12.30
C2	7.65
Total	100

and the area of conflict resolution are the two where the percentage of basic level is higher than intermediate. In this area, the percentage of basic level is close to 50%, being 46.66% divided into 22.39% for level A1 and 24.27% for level A2. Thus, this area is the worst rated according to the students. The basic level is followed by the intermediate level with 40.39% of pupils. Finally, the percentage of pupils who consider that their teachers have an advanced level in problem solving is 12.94% (Table 5).

Gender and digital skill

In order to analyze the H1: There are statistically significant differences between students' gender and the level of digital competence they perceive from their teachers. The four cases (1.30%) of people who identified with the non-binary gender were discarded, so as not to harm the statistical power of the test. With the remaining data, the Kolmogorov-Smirnov normality test was calculated and, since there are significance values $p < 0.05$, the Mann–Whitney U-test was found to apply. This rejects H1, as there are no statistically significant differences; in all cases $p > 0.05$ (Table 6).

Age and digital skill

Pearson's correlation was calculated in order to analyze the H2: There is a correlation between students' age and the level of digital competence they perceive from their teachers. H2 is rejected, as age is not correlated with the perceived level in any of the five competence areas ($p > 0.05$) (Table 7).

Knowledge branch and digital skills

In order to analyze the H3: There is an association between students' branches of knowledge and the level of digital competence they perceive in their teachers. The Kolmogorov-Smirnov normality test was applied and given that there are significance values $p < 0.05$, it was found that the Kruskal–Wallis H-test should be applied. The results of this test, shown in Table 8, indicate that there are statistically significant differences only for competence 1 (Digital Competence in Information and Information Knowledge). Within this competence, the Mann-Whitney U test identified statistically significant differences only when comparing two of the five branches of knowledge, the difference appears between Health Sciences and Social and Legal Sciences ($U = 2324.5$, $Z = -2.746$, $p = 0.006$; for other two-by-two comparisons, always $p > 0.05$).

TABLE 5 Evaluation of the area of problem solving.

Level	Percentage
A1	22.39
A2	24.27
B1	22.56
B2	17.83
C1	8.14
C2	4.80
Total	100

Attendance and the digital skill

To analyze the H4: There is a correlation between the mode of course attendance and the level they perceive of their teachers. Those students who attended the face-to-face classes were excluded, as there were only 4 people. For the rest, Kolmogorov-Smirnov normality tests were applied. In several cases, $p < 0.05$ was obtained, so a Kruskal–Wallis H-test was applied to compare the means. The results of this test, shown in Table 9, indicate that there are no statistically significant differences between the responses obtained in the different assistance modalities.

Self-perceived digital skills and the evaluation of the professors

As for the H5: There is a correlation between students' self-perceived level of digital skill and the level they perceive of their teachers, was analyzed by calculating Kendall's tau correlation coefficient. For none of the competences a significant correlation coefficient was obtained (Table 10).

Discussion

The digital skills are one of the most useful for this modern society. The European Union is one of many institutions that are engaging the educators to start working on that. In 2019, they highlight how the digital native have easier learning concepts with ICT but if they wanted to develop new skills related to them, they need and educator the guides them to develop the skill properly (European Comisión, 2019).

For that the university must be the main institution to teach the digital skills. However, the digital skills level of university teachers does not meet the expectations placed upon them. There is a feeling amongst lecturers that their own level is B1 or B2 (Mora-Cantallops et al.2022), which is defined according to the Marco Común de Competencia Digital Docente as an intermediate level, although this is sufficient for their own work, it is a deficient level for university lecturers, as they are

TABLE 6 Analysis of the association between gender and level of digital skills.

	Contrast statistics				
	Skills area 1	**Skills area 2**	**Skills area 3**	**Skills area 4**	**Skills area 5**
Mann–Whitney's *U*	9,149.500	9,168.000	8,747.500	9,352.500	9,116.000
p-value	0.590	0.609	0.263	0.806	0.557

TABLE 7 Analysis of the correlation between age and level of digital skills.

		Skills area 1	**Skills area 2**	**Skills area 3**	**Skills area 4**	**Skills area 5**
AGE	Pearson correlation	−0.031	−0.011	−0.040	−0.014	−0.007
	p-value	0.586	0.848	0.487	0.809	0.905

TABLE 8 Analysis of the association between the branch of knowledge and the level of digital skills.

	Contrast statistics				
	Skills area 1	**Skills area 2**	**Skills area 3**	**Skills area 4**	**Skills area 5**
Chi-square	9.842	7.593	8.675	2.171	5.793
gl	4	4	4	4	4
p-value	0.043	0.108	0.070	0.704	0.215

TABLE 9 Analysis of the association between mode of attendance and the level of digital skills.

	Contrast statistics				
	Skills area 1	**Skills area 2**	**Skills area 3**	**Skills area 4**	**Skills area 5**
Chi-square	2.193	2.878	2.381	2.494	3.997
gl	2	2	2	2	2
p-value	0.337	0.243	0.311	0.286	0.140

TABLE 10 Analysis of the correlation between self-perceived digital competence and the level of digital skills.

		Skills area 1	**Skills area 2**	**Skills area 3**	**Skills area 4**	**Skills area 5**
Self-perceived	Kendall's correlation	0.032	0.022	0.016	0.005	0.025
	p-value	0.477	0.618	0.722	0.906	0.584

responsible for transmitting this type of knowledge to a large part of the Higher Education students. On the part of the students, their opinion coincides with this idea, as the students' assessment reflected a score similar to that self-perceived by the lecturers.

The evaluation proposed by the students is very similar regardless of the characteristics of the students. Aspects such as gender are not a decisive factor in determining teachers' ratings. If surveys are carried out on individual teachers of different sexes to assess teachers' digital competences, there are generally no differences in their assessment on a quantitative level (Boring, 2017). When analyzing the qualitative level, more negative comments can be distinguished for female teachers than for male teachers (Tangalakis et al., 2022). In the results presented, it can be seen that there is no variation at the quantitative level according to the sex of the students, although it could be analyzed whether the type of comments made also varies according to the gender of the students.

Age is established as a determining factor regarding the use of technology. This is an important factor, as it is a way of identifying those students who have grown up in an environment where ICT is an element of the immediate environment or if it has been added as the person has developed. According to the average and mode of the students, it can be determined that the majority of students were born between 2001 and 1999, so they can be considered as digital natives (Aguilar-Salinas et al., 2019). However, there is no significant difference between students who were born during this period and those who are older. This shows that regardless of whether pupils are considered digital natives or not, as they are common

elements in their lives, teachers are not able to develop the usage of different digital devices in the education process.

This idea is reinforced by the analysis of the assessment of students according to their level. The students' self-perceived level is similar to that of the teachers. However, there are groups of students who are more qualified and other groups who consider them to have basic knowledge. This difference in level would be expected to make a difference in the assessment. The analysis shows that regardless of the level of the students, the assessment is the same, and does not meet the expectations of either the most qualified students with basic knowledge.

Another aspect to take into account when evaluating digital competences is the branches of knowledge. Depending on the degree being studied, there may be different expectations, as the training plans for each degree vary. Therefore, the grouping by branches of knowledge can be used as a reference to visualize which aspects are more developed and which need further reinforcement. The comparison between branches does not show a significant difference except for a comparison between Social and Legal Sciences and Health Sciences. If a search is made in the scientific literature, a possible explanation that is pointed out by Fuentes et al. (2019), as it is mentioned that in the case of the Social and Legal Sciences, the area of Information and Information Knowledge is the priority area, so much of the training in the degrees of this branch is focused on this aspect, which may generate the difference when compared with other branches.

Finally, COVID-19 has exposed the deficiencies regarding this type of skills, as with the onset of the pandemic, people's mobility was reduced, making face-to-face attendance at the different educational institutions impossible. The transition from an entirely face-to-face education to an education leads to negative assessments on the part of the students (García-Planas and Taberna Torres, 2020). However, some of the students during this period had the opportunity to attend lectures face-to-face different subjects, while others were only able to do so online. Comparing the assessment of the students, no significant differences are shown, so it may be that the conversion from face-to-face to online has negatively affected the assessment of the students, but if it is compared the online lectures with attending only face-to-face to the practical part of the subjects does not effect on the student's perception.

The European Union encourage the promotion of digital skills. The possibility of being able to develop useful digital skill that allows the correct participation of the user and the relationship with the environment, this being a right (European Parliament and the Council, 2006; Durán Cuartero et al., 2019). Spain, for its part, has generated a reference framework that serves as a guide to identify the minimum knowledge that must be obtained as an educator. It is necessary for teacher training however, especially for university teachers, to include specific training that helps teachers to develop a good level that makes it possible to transmit knowledge to students.

Conclusion

Students at the University of Granada have a unanimous opinion regarding professors' digital skills. Among the different factors that could divide the students' opinion, there is none that stands out as giving a significant variation, so it can be said that the university students' assessment is that their teachers have an intermediate level. This level is sufficient for a large part of the population. University teaching staff, however, belong to a group in society that require a high level of proficiency in this skill, as they are responsible for transmitting knowledge to a large part of Higher Education. For this reason, university teacher training processes should include certification of digital skills.

On the other hand, when discarding the hypotheses, since it has been shown that the characteristics of the pupils do not influence their assessment of their teachers, it would be advisable to go deeper into the study itself. The results shown give an insight into the quantitative assessment that pupils have of their teachers. Adding a qualitative section however is a possible improvement of the present study to see if the characteristics of the students do change the comments made, as well as to see specifically what the students' demands are and which of their needs are not being met.

It was also mentioned how the different university branches have different needs; therefore, teacher training should meet the requirements of the different branches. It was mentioned how in the branch of Social Sciences and Law the area of Information and Information Literacy teacher training is more encouraged. This is a good dynamic for students to improve their perception, as students will receive specific training according to their needs and expectations.

After analyzing and reviewing the results, it can be affirmed that the University of Granada does not have an adequate teaching development plan according to its students. Therefore, specific subjects for the development of digital skills should be considered as part of this process. Subsequently, further research can be carried out to analyses whether this implementation leads to an improvement in academic results and student evaluation.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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Conflict of interest

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

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The impact of the digital divide on synchronous online teaching in Kazakhstan during COVID-19 school closures

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This paper examines how factors associated with the digital divide such as ICT access, digital skills, and outcomes influenced synchronous online teaching in urban and rural schools in Kazakhstan during COVID-19 school closures. In addition to school location, this paper addresses how the speed and steadiness of the internet connection, and teacher characteristics such as age, qualification, and experience influenced teacher usage of synchronous teaching and learning mediums. Data in this paper consists of a nationally representative sample of nearly 4,000 teachers. This study found that the digital divide narrows when schools provide teachers with ICT access. While both, the speed of the internet and rural–urban residency have statistically significant effects on the use of ICT tools by teachers when considered separately, the interaction term between these two covariates was not statistically significant. Results indicated that age, experience, teacher workload and professional qualification were important determinants in teachers' ability to engage in synchronous teaching.

KEYWORDS

teachers, online teaching, digital divide, COVID-19, online survey, Kazakhstan

Introduction

Full and partial school closures due to COVID - 19 pandemic from March 2020 to January 2021 globally averaged 22 weeks, which is two-thirds of an academic year (UNESCO, 2021). This extraordinary global situation created a natural experiment allowing us to evaluate the resources available for remote learning and the digital divide that may exist for teachers and students. The digital divide embodies the inequality between those with technology access and digital skills and those without (Hartviksen et al., 2002; Van Dijk, 2006; Ragnedda and Kreitem, 2018). The current paper focuses on how the digital divide manifested itself during COVID – 19 induced remote learning and teaching in Kazakhstan, the largest country in Central Asia. Full and partial school closures in this country amounted to 32 weeks between March 2020 and January 2021 (UNESCO, 2021).

Research shows that the massive shift toward distance education could exacerbate existing educational inequalities (Hosszu and Rughinis, 2020; Quaicoe and Pata, 2020; Darmody et al., 2021; González-Betancor et al., 2021; León-Nabal et al., 2021). The challenges associated with technology and internet access shape how teachers and students engage in online learning. Lack of reliable data on who has access to online education and digital infrastructure as well as professional development for teachers pose an additional challenge for low- and middle-income countries (Crompton et al., 2021; Hennessy et al., 2022). These countries are novice to digital education and less aware of what technology can offer and achieve in learning and teaching.

In this context, the case of Kazakhstan is interesting for several reasons. Over the past decades, Kazakhstan has invested heavily in modernizing its education system (Ibrayeva, 2014) and digitalization (Digital Kazakhstan, 2018; Klymenko and Alpeissova, 2021). It has transitioned from lower-middle-income to upper-middle-income country status in less than two decades (World Bank, 2021). The geography of the education system consists of densely populated regions and regions with one of the lowest population densities in the world (Hambly, 2021). Although the government is racing to digitalize the country (Digital Kazakhstan, 2018), access to ICT remains uneven (UN Economic and Social Commission for Asia and the Pacific, 2020). Research has shown that issues associated with the digital divide, such as slow internet, and lack of proper equipment, were dominant challenges for parents in Kazakhstan during COVID-19 forced school closures (Bokayev et al., 2021a). A lack of effective interaction between educational stakeholders presented an additional challenge to address at least some of these issues promptly (Kovyazina et al., 2021; Bokayev et al., 2021b).

To better understand which factors characteristic of the digital divide conditioned the quality of online teaching in Kazakhstan, this paper seeks to examine how teachers during school closures in fall 2020 engaged in synchronous teaching using programs like Zoom, Microsoft Teams, Skype, Google Meet, and others. Online learning sets two basic formats, asynchronous and synchronous in what the difference refers to the time and place of educational activities. Asynchronous environments are characterized as being more individual-oriented, self-regulated, and less teacher-dependent, while synchronous online teaching means teachers use video-conferencing systems, including Zoom and Google Meets, to deliver lessons in real time (Fabriz et al., 2021; Wang and Wang, 2021; Stuart et al., 2022).

Among the major benefits of synchronous learning and teaching are the availability of verbal and non-verbal language, instant feedback and real-time interpersonal communication (Blau et al., 2017; Moorhouse and Wong, 2022). Given the interactivity factor of synchronous learning, we consider this mode essential for teachers to support students who are deprived of learning opportunities at school and might have difficulties with self-regulated learning while at home.

Literature finds that benefits of synchronous and asynchronous learning can be different for different age groups. Learning asynchronously might be more advantageous due to its flexibility, accessibility and learner-centredness and might be more suitable for university students because they are more likely to have better self-study skills and practice more self-regulation (Davies et al., 2020; Schreiber et al., 2022). For school-age children, which is the education level in the focus of this paper, synchronous learning is more beneficial because they are accustomed to learning with a teacher guiding and instructing them. Research also demonstrates that synchronous teaching has positive impacts on academic outcomes (Stuart et al., 2022), more feedback and greater support (Fabriz et al., 2021), and task motivation (Hrastinski et al., 2010).

This paper hence focuses on synchronous teaching and examines how it was associated with the digital divide. The paper examines this phenomenon through the focus of digital infrastructure such as the steadiness of the internet connection, and teacher characteristics such as age, qualification, and experience. The data analyzed in this paper comes from a survey of about 4,000 teachers, a nationally representative stratified random sample, conducted in the fall of 2020. Results of this research contribute to better understanding of factors critical to narrow the digital divide of access, skills and outcomes in the context of synchronous learning and teaching. As such, these results can inform better national and local-level decisions in supporting teachers and overcoming negative effect of digital divide in education.

Literature review

Conceptualization of the digital divide

The digital divide represents unequal access to the internet and digital affordances, occurring at individual, local, national, and international levels. It generally defines the gap "between those who do and those who do not have access to new forms of information technology" (Van Dijk, 2006, p. 222). In other words, the digital divide embodies the inequality between those with technology access and digital skills and those without. The focus in digital divide research has transitioned from inequalities of access to digital skills and usage, addressing the limitations of the past research that mainly referred to binary differences between haves and have-nots (van Deursen and van Dijk, 2014). For a long time, the digital divide was commonly seen as a technical issue rather than as an amalgam of deeper social problems (Light, 2001; Dijk et al., 2003). However, mere access to technology and infrastructure does not reflect the complex nature of the digital divide. Researchers (Hargittai, 2002; Van Dijk, 2006; Wei et al., 2011; Ragnedda and Kreitem, 2018) define three dimensions of digital inequality – digital access divide, digital capability divide, and digital outcome divide. This classification illustrates the multidimensional nature of the digital divide phenomenon that goes beyond mere technical metrics.

In the modern world, *digital access,* also known as material or physical access to ICT (Van Dijk, 2006), can be considered as one of the basic human rights because of the growing internet connectivity and ICT ownership. In addition to unequal access, *digital skills and capabilities* play an important role in determining to what extent people navigate the internet and technology confidently and safely. The biggest issue has become how well people are equipped with the skills necessary for the digital world. New terms have emerged to describe the skills focus, including "internet use," "social media use," "digital literacy and competencies," to name the most ubiquitous (van Deursen and van Dijk, 2014).

Digital skills and access to ICT lead to the third aspect of the divide – *the digital outcome*. The digital outcome divide "underlines inequalities in the benefits gained from the different levels of access and usage of the Internet" (Ragnedda and Kreitem, 2018, p. 8). Individuals affected by this divide lack belief and self-efficacy, resulting in lower digital productivity (Mathrani et al., 2021). It leads to differences between people in learning outcomes and purposeful ICT usage (Wei et al., 2011; van Deursen and Helsper, 2015). Nevertheless, notes Scheerder et al. (2017), the digital divide research primarily focuses on access and skills divides, giving little attention to examining the benefits, outcomes, and effects of technology use (van de Werfhorst et al., 2020).

The three aspects of digital inequality - digital access, capability, and outcome divide - are relevant when assessing its effects on education. COVID-19 pandemic in 2020 when education systems in the world experienced a massive shift to remote and online education exacerbated the relevance of these three aspects of digital divide. To understand the effects of digital divide on teaching and learning, it is important to focus on not only the first crucial step, access to ICT, but also ICT literacy and outcomes measured as results of remote learning. This paper attempts to examine these three aspects of the digital divide in education by understanding what factors determine teacher use of synchronous programs like Zoom and others to support student learning and achievement.

Factors contributing to digital divide internationally and in Kazakhstan

The digital divide reflects broader contextual factors such as social, economic, cultural, and learning inequalities. As such, factors contributing to the digital divide are economic, social, ethnolinguistic, and infrastructural (Bagchi, 2005). Social groups in marginalized or minority positions are more likely to experience the negative effects of the digital divide. Inequalities in ICT access also manifest in urban and rural dimensions. Online education might increase the existing gaps between rural and urban populations whose access to online education significantly differs (Hosszu and Rughinis, 2020). It is true for Kazakhstan as well since the urban–rural divide remains unsolved across many areas of social life including digitalization (OECD, 2017). The overall share of internet and ICT access reported for cities in 2016 was 81.3 and 70.9% in the rural settlements of Kazakhstan. Despite these relatively high percentages of internet connectivity, access to high-speed internet remains uneven in favor of urban areas over rural locations (Digital Kazakhstan, 2018).

Other factors signaling the possible risk of experiencing negative effects of the digital divide are a person's age and educational background (Ertl et al., 2020). Age is the most obvious factor that puts older people at a disadvantage in using digital technology. Starkey et al. (2017) refer to the generational gap between younger and older people that gives the space for a deficit model of ICT use in education. Indeed, teachers at younger ages show greater digital competencies over their more senior colleagues (Kale and Goh, 2014; Cantú-Ballesteros et al., 2017). Although experts note that the digital gap between young and older people does not seem to be closing in the near future (Enoch and Soker, 2006), professional development programs for teachers can offer a solution. Teachers who participate in professional development gain confidence in ICT usage (Pongsakdi et al., 2021), tend to use computers in class more often, focus more on teaching ICT skills and develop stronger ICT self-efficacy (Drossel and Eickelmann, 2017).

According to Teaching and Learning International Survey (TALIS, 2018), seven in 10 Kazakhstani teachers reported having "ICT for teaching" as part of their formal education or training, and almost all of them reported participation in professional development within the last year (OECD, 2019). At the same time, more teachers in Kazakhstan (30%) than in OECD countries (18%) reported a high need for professional development in ICT use (OECD, 2019). These contradictory results suggest the need for more effective pre-service and in-service teacher training in ICT usage for those who are digital novices in education in Kazakhstan to reduce digital inequality affecting education.

Education level is one more factor associated with the digital divide. People with higher levels of education are likely to be more competent at using computers and the internet. Research indicates that during the early years of digital expansion, people with college or higher degrees were 10 times more likely to have internet access at work than those with only a high school certificate (NTIA, 1998). While there is broad internet access today, individuals with university degrees appear to reap more ICT-related benefits than those who hold lower educational qualifications. Highly educated people seem to have better digital skills, which also empower them to be more productive while using ICTs (Correa, 2015; Azubuike et al., 2020). Teachers in Kazakhstan generally hold a bachelor's degree and thus belong to those highly educated; teachers with a vocational or college education in pedagogy can still work in primary schools. At the same time, recent data shows that only about two-thirds of teachers have reported feeling prepared to use ICT in teaching after completing their formal studies in Kazakhstan (OECD, 2019).

Research before the COVID-19 pandemic showed that lack of teaching experience with ICT, absence of on-site support for teachers using technology, lack of help supervising children when

using digital tools, insufficient technology training for students at school, limited availability of computers, the time required to integrate technology into the curriculum successfully, and inadequate financial incentives may all hinder teachers' ability to effectively use ICT in their teaching (Mumtaz, 2000; Ekberg and Gao, 2018; Mynarˇíková and Novotný, 2021). With the pandemic-affected school closures, these obstacles did not vanish. The digital divide became an integral variable affecting the education process. The current article will proceed to examine how factors associated with the digital divide manifested in the use of synchronous online teaching mediums (e.g., Zoom) among teachers in Kazakhstan.

Materials and methods

Data

In this article, we use data from a large-scale online survey of mainstream schoolteachers conducted in Kazakhstan from October to November 2020 as part of the monitoring of distance learning in the country, commissioned by the Information Analytics Center (IAC) and approved by the Ministry of Education in Kazakhstan. IAC is a publicly-funded think tank tasked with conducting analytics and research to inform educational decision-making and policy.

Survey

The survey sampling design consisted of one-stage stratified sample with the proportional allocation of teachers to rural, urban and regional settings. Stratification was conducted according to Kazakhstan's rural–urban area and official administrative division, resulting in 31 explicit strata. Four thousand teachers were allocated proportionally among explicit stratum with subsequent random sampling from the list of teacher population. The sampling frame used for selection was taken from the National Educational Database, which contains administrative data from all schools in the country. Before taking the survey, teachers invited to participate were provided with information on data use, anonymity, and confidentiality. Only those respondents who after viewing this information clicked "Yes" in the dialog window, answering a straightforward question about their willingness to participate in the survey, proceeded to answer other questions in the survey.

The survey questionnaire was specifically developed to examine how various socio-demographic characteristics of teachers are associated with the use of ICT, access to ICT, teaching in general and teaching to specific groups of students such as students with special educational needs, evaluation of the effectiveness of distance learning, and satisfaction with distance learning after switching to remote learning in Spring 2020 and continuing remote teaching in Fall 2020. To obtain additional variables on professional characteristics of teachers such as professional category, workload and experience, we combined survey data with data from the sampling frame taken in turn from National Education Data Base (NEDB).

Variables

To answer the research question guiding this paper - how synchronous online teaching was associated with the urban or rural school location, the speed and steadiness of the internet connection, and teacher characteristics such as age, their qualification and experience – we used a 5-point Likert scale item with ordered categories (never, rarely, sometimes, often, and always) representing a frequency of video programs such as Zoom, Microsoft Teams, Skype, Google Meet used for synchronous teaching during Spring 2020 as the dependent variable. The distribution of answers for each category was 10.6% (never – one or two lessons), 11.3% (rarely – in some lessons), 26% (sometimes - in some lessons), 28.4% (often – in several lessons) and 23.3% (always – every lesson).

Regarding the digital divide, our main explanatory variables were the reported speed of internet connection, availability of home PC/laptop, availability of school PC/laptop and rural–urban place of living. The question on the internet consisted of five ordered categories with percentages of answers for "very high speed: fast download of video and online lessons: no lagging" – 17.6%, "high speed: with some lagging" – 29.1%, "average speed: need to wait" – 43.5%, "low-speed: almost impossible to watch" – 8.1% and "very-low speed: cannot open the video" – 1.6%. The categories were recorded in increasing rather than decreasing order, in the analysis we used the speed of the internet with five categories as a continuous variable. Although in some cases the use of Likert scale data in the parametric analysis is questionable (Lantz, 2013), there is a strand of research supporting the use of the categorical ordinal scales with at least five categories and a large enough sample size as continuous, interval in the parametric analysis (Hsu and Feldt, 1969; Carifio and Perla, 2007; Norman, 2010; Harpe, 2015).

Availability of school PC/laptop and home PC/laptop are represented as dichotomous items with Yes/No categories with the distribution of answers 36%/64 and 95.5%/4.5%, respectively. We expect a positive relationship between the reported speed of the internet and the use of video programs, faster internet connection leading to higher use of video programs. In line with this hypothesis, the availability of home and/or school computers should positively affect the use of ICT video tools for teaching as well.

Furthermore, we use rural or urban places of residence with 55% of respondents and 44.9% of respondents, respectively. To measure the difference between the rural and urban speed of internet connection, we construct an interaction between the two variables. If unequal access to the internet across rural and urban teachers holds, we expect a higher reported speed on the internet

for urban teachers and as a result higher use of ICT video tools by urban teachers.

We include age and education to account for teachers' socio-demographic characteristics. Education is represented by five categories starting with secondary (school level) and ending with a post-graduate degree (PhD). However, due to a significant imbalance between categories (Table 1), we recode education into a dichotomous variable with 1 for teachers with university degrees and 0 for teachers with secondary education and college degrees. The resulting distribution is 91.1% for the first group and 8.9% for the second. Age is a continuous variable with an unweighted sample mean of 40 and a standard deviation of 11. In line with Cantú Ballesteros et al. (2017), we expect that age is negatively associated with the use of online ICT video programs; older teachers use tools for synchronous teaching less than younger teachers. At the same time, education is expected to be positively related to the use of ICT programs; teachers with a university degree are more likely to use ICT tools than teachers who do not have a university degree.

The final set of independent variables consists of teachers' professional qualifications and professional category achieved, teaching experience measured in years, and workload measured in teaching hours. In Kazakhstan, professional categories for teachers can be combined into four groups, from the lowest to the highest category. We code them from 1 to 4 with 4 representing teachers with the lowest category. Teacher's categorization is specific to Kazakhstan's educational context and reflects the teacher's seniority, achievements, and professional development (Minister of Education and Science, Republic of Kazakhstan, order nr. 192, 2020). Descriptive statistics for continuous variables such as age, experience and workload are given in Table 2, whereas the distribution of teachers for categorical variables (education, professional category) is given in Table 1. We deleted the missing values by using the listwise deletion, thus the original dataset with 3,349 observations was reduced to 3,029 observations.

To avoid potential issues of multicollinearity due to the introduction of the interaction term into the analysis, we run the model using both, centered and non-centered data. For the centered case, we followed the centering strategy proposed by Kraemer and Blasey (2004). More specifically, all dichotomous variables were coded as +1/2 (+0.5) and − 1/2 (−0.5), whereas all continuous and ordinal were centered around median values. The categorical variable representing the teacher professional category was dummy coded with subsequent coding 1-1/m for 1 and − 1/m for 0. Regression results of the non-centered data are presented in Table 3. The regressions were calculated on the unweighted data, models with the weighted data produced non-convergent solutions.

TABLE 1 Distribution of teachers' answers in categorical variables (n=3,029).

Education	Professional category
Secondary (2.6%)	Highest (26.9%)
Technical and professional – college (6.4%)	High (29.7%)
Higher – bachelor (86.5%)	Medium (22.7%)
Higher – master (4.3%)	Low (21%)
Post-graduate – PhD (0.2%)	

Data analysis

Since the dependent variable is categorical ordinal, proportional odds ordinal logistic regression (McCullagh, 1980) was used in the analysis with subsequent Brant test to check whether the proportional odds assumption holds across the categories of the dependent variable (Brant, 1990; Long, 1997).

In case any of the regression coefficients are not equal across categories the proportional odds assumption is violated and it is more appropriate to use partial proportional odds models,

TABLE 2 Descriptive statistics for continuous variables (n=3,029).

Variable	Min.	Median	Mean	Max.
Age	19	40	40.86	73
Experience	0	11	14.04	51
Workload	0	1.00	1.064	2.00

TABLE 3 Results of ordinal logistic regression models (non-centered solution, n=3,029).

Variable		Model 1	Model 2	Model 3
Rural–urban (rural)		−1.09 (0.27)***	−1.13 (0.27)***	−0.96 (0.27)***
Age			−0.01 (3e-3)**	−0.03 (4e-3)***
Education			−0.11 (0.07)	−0.07 (0.07)
Speed on internet		0.33 (0.06)**	0.31 (0.06)	0.31 (0.06)
School PC/Lap (No)		−0.27 (0.07)***	−0.27 (0.07)***	−0.28 (0.07)***
Home PC/Lap		−0.30 (0.16)	−0.31 (0.16)	−0.28 (0.16)
Experience				0.02 (5e-3)*
Workload				0.68 (0.12)***
Interaction: rural–urban and speed of Internet		0.07 (0.07)	0.09 (0.07)	0.08 (0.07)
Category	2			−0.34 (0.09)***
	3			−0.36 (0.11)***
	4			−0.50 (0.12)***
1|2		−1.73 (0.22)***	−1.82 (0.33)***	−2.26 (0.40)***
2|3		−0.83 (0.22)***	−0.92 (0.33)***	−1.35 (0.40)***
3|4		0.45 (0.22)*	0.37 (0.33)	−0.04 (0.40)
4|5		1.81 (0.22)***	1.73 (0.33)	1.35 (0.40)**
AIC		8985.90	8979.52	8910.16

*p < 0.05; **p < 0.01; ***p < 0.001.

generalized ordered or multinomial regression models (Fullerton, 2009). Further, to test ordinal regression goodness-of-fit we used McFadden, Nagelkerke and Cox-Snell pseudo-R square coefficients (McFadden, 1974; Cox and Snell, 1989; Nagelkerke, 1991) along with Pulkstein-Robinson deviance and chi-square tests, Hosmer Lemeshow, and Lipsitz likelihood ratio tests (Fagerland and Hosmer, 2017). In addition, we looked at Akaike Information Criterion (AIC) to compare different models (Akaike, 1972) and conducted likelihood ratio tests to see whether the addition of variables led to improvement in model fit (Vuong, 1989).

All data analysis in this paper was onducted in R statistical programming software (R Core Team, 2020). We used polr function from MASS package to run ordinal regression model analysis (Ripley et al., 2022), DescTools package for pseudo-R square coefficients (Signorell, 2021), generalhoslem for calculation of goodness-of-fit statistics (Jay, 2019), effects for calculation of predicted probabilities from ordinal regression models (Fox, 2022) and ggplot2 for the visualization of results (Wickham et al., 2022).

Overall, we consequently calculated three separate models. In the first model, we used the reported speed of the internet, geographic location, the interaction between them, and the availability of school and home PC/laptops. In the second model, we added age and education. The third model added experience, workload, and teachers' professional category. The indicators of model fit AIC showed a gradual decrease from model 1 to model three from 8,989 to 8,910 (Table 4). The same positive increase can be pointed out across all pseudo-coefficients, with Nagelkerke showing an increase from 0.11 to 0.13 (Table 5). Furthermore, large p-values ($p > 0.05$) indicated a good fit for model 3 according to all four goodness-of-fit tests (Table 6). Finally, the likelihood ratio test showed a statistically significant difference of 0.0006 between model 1 and model 2 and between model 2 and model 3 (1.08e−14), meaning that the inclusion of socio-demographic characteristics and professional qualification variables led to the improvement in model fit. Regarding the proportional odds assumption Brant test showed large p values (> 0.05) for the omnibus test as well all variables in model 3 except the availability of Home PC/Lap meaning that the proportional odds assumption was satisfied, and the effects of the regression coefficients were the same across the categories of the dependent variable.

TABLE 4 Results of ordinal logistic regression models (centered solution, n=3,029).

Variable		Model 1	Model 2	Model 3
Rural–urban (urban)		0.86 (0.08)***	0.87 (0.08)***	0.72 (0.08)***
Age			−0.09 (0.03)**	−0.37
				(0.05)***
Education			−0.05 (0.11)	−0.13 (0.12)
Speed on Internet		0.34 (0.03)***	0.33 (0.03)***	0.33 (0.03)***
School PC/Lap (yes)		0.27 (0.07)***	0.27 (0.03)***	0.28 (0.07)***
Home PC/Lap		0.30 (0.17)	0.32 (0.16)	0.28 (0.17)
Experience				0.02 (5e-3)***
Workload				0.21 (0.03)***
Interaction: rural–urban and speed of Internet		−0.07 (0.07)	−0.08 (0.07)	−0.08 (0.07)
Category	2			−0.34
				(0.09)***
	3			−0.37
				(0.11)***
	4			−0.52
				(0.12)***
1|2		−2.02	−2.04	−1.86
		(0.10)***	(0.11)***	(0.12)***
2|3		−1.11 (0.09)**	−1.14 (0.10)	−0.95 (0.12)
3|4		0.17 (0.9)	0.14 (0.10)	0.35 (0.11)***
4|5		1.53 (0.09)***	1.51 (0.10)***	1.75 (0.12)***
AIC		8989.52	8985.55	8910.37

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

TABLE 5 Goodness-of-fit statistics for each regression model (centered solution, n = 3029).

	Model 1	Model 2	Model 3
McFadden	0.03	0.04	0.04
Nagelkerke	0.11	0.11	0.13
CoxSnell	0.10	0.10	0.13
	Goodness-of-fit tests (p-values)		
PR deviance	0.14	0.59	0.44
PR chi-square	0.21	0.63	0.60
HL	0.47	0.60	0.89
L	0.22	0.13	0.46

Results

This section presents the results of three fitted models analyzing how access to ICT, socio-demographic and professional characteristics of teachers impacted teachers' engagement in remote synchronous teaching (Table 4). We interpret a marginal change on one unit simultaneously, holding other continuous variables constant and categorical variables at their reference categories. Results are considered to be statistically significant based on the size of standard errors (s.e.) relative to the regression coefficient (β), if two standard errors do not include zero, then one can safely claim that a coefficient is statistically significant.

In the first model, there is a statistically significant effect of dummy coded rural–urban area, more specifically for urban teachers, who do not have an access to the school computers, the log odds of being in a higher category of ICT video tools use is 0.86 (s.e. = 0.08) higher than for rural teachers. With regards to the speed of the Internet, the effect for rural teachers is statistically significant, a category increase in the reported speed of the Internet leads to 0.34 (s.e. = 0.03) increase in the log odds of being in a

TABLE 6 Marginal predicted probabilities of model 3 (min-max/max-min change).

	Probability for each category				
	Never %	Rarely %	Sometimes %	Often %	Always %
Rural–urban	0.12–0.06	0.13–0.08	0.30–0.24	0.28–0.33	0.17–0.28
Age	0.05–0.23	0.06–0.20	0.19–0.31	0.33–0.19	0.37–0.08
Speed of internet	0.19–0.06	0.18–0.70	0.31–0.23	0.21–0.33	0.10–0.31
Experience	0.11–0.05	0.13–0.07	0.30–0.22	0.29–0.33	0.18–0.33
Workload	0.16–0.05	0.16–0.07	0.31–0.22	0.24–0.33	0.12–0.33
Category 2	0.08–0.11	0.10–0.13	0.27–0.30	0.31–0.28	0.23–0.17
Category 3	0.08–0.12	0.10–0.13	0.27–0.30	0.31–0.28	0.23–0.17
Category 4	0.08–0.13	0.10–0.14	0.27–0.31	0.31–0.26	0.23–0.15
School PC/Lap	0.10–0.08	0.12–0.10	0.29–0.26	0.30–0.32	0.20–0.25

higher reported category of ICT tools used for online teaching, holding everything else constant. However, the interaction of locality and speed of the Internet does not show a statistically significant effect, with the two standard errors being larger than the regression coefficient and covering 0 ($\beta = -0.07$, s.e. = 0.07). Moreover, while the availability of a home PC/laptop is not statistically significant, access to school PC/laptop for rural teachers positively affects the use of online video tools ($\beta = 0.27$, s.e. = 0.07).

In the second model, age indicates a statistically significant negative effect ($\beta = -0.09$, s.e. = 0.03), nonetheless, teachers' education does not have a substantial impact on the use of ICT video tools for teaching ($\beta = -0.05$, s.e. = 0.11). However, one must keep in mind that the majority of teachers (90%) in the sample are with higher education degrees which could influence the estimates in the regression model. At the same time the type of locality ($\beta = 0.87$ - urban) and speed of the Internet ($\beta = 0.33$) continue to show statistical significance (s.e = 0.08 and s.e = 0.03), whereas interaction between them does not ($\beta = -0.08$, s.e. = 0.07).

The third model highlights the statistical effects of the group of variables related to professional characteristics. More specifically, more experienced, rural teachers with the highest professional category, without the access to school computers, tend to report a higher use of video tools for online lessons with the log odds coefficient of 0.02 (s.e. = 0.005). The same could be said about the workload where an increase in workload for a rural, teacher with the highest professional category and without the access to school PC, leads to 0.21 increase in the log odds of being in the group of the teachers with higher reported use of video tools as opposed to the group with lower reported use of video tools (s.e = 0.03). Furthermore, the results show statistically significant negative effects of dummy coded professional categories, the coefficients for categories 2, 3, and 4 ($\beta = -0.34$, $\beta = -0.37$, $\beta = -0.52$ respectively) are negative, meaning that rural teachers without the access to school computers with lower professional categories tend to report the lower frequency of use of video tools for online lessons as opposed to their colleagues with the highest category (reference category).

In other words, more senior teachers by the qualification category used ICT tools for synchronous teaching more than their junior colleagues in terms of the professional qualification category. At the same time, an increase in teachers' workload and years of experience led to the increase in the use of ICT tools, whereas education, although highly imbalanced toward teachers with bachelor and master degrees, indicated no statistically significant effect. Surprisingly one of the main variables measuring digital divide – interaction between rural–urban locality and the speed of Internet did not show significance across all three models, while independently, both variables show statistically significant effects. In addition, the results indicated the importance of school PC/laptop availability for online synchronous teaching as opposed to home PC/laptop, which is not significant across all three models.

Table 6 gives percentage change between the minimum and maximum marginal predicted probabilities for statistically significant explanatory variables in model 3. More specifically, urban teachers have 11% more probability (0.28) of always using ICT video for synchronous class instruction each lesson than rural teachers (0.17). There is a 12% difference (0.21–0.33) between very low and very high reported speed of Internet with regards to teachers who often use ICT video tools for synchronous teaching. On average, the availability of school PC/laptops increases the use of ICT tools for synchronous online teaching by 2 (categories never, rarely, and often) to 5 (categories sometimes and always) percent. The above-mentioned effects are presented in Figures 1, 2.

The non-centered solution (Table 3) did not substantially change the results of the modeling. The solution is almost similar to the model with centered predictors with the same statistical significance and direction of the regression coefficients for age, speed of Internet, school PC/lap, experience, and category. With almost everything being equal, we nonetheless stick to the output of the centered solution as it provides more stable estimates than the non-centered solution. More specifically the logit regression coefficients of rural–urban and teachers' workload variables have larger standard errors (s.e. = 0.27 and s.e. = 0.12) in the non-centered as opposed to the centered solution (s.e. = 0.08 and s.e. = 0.03), although in both cases the regression coefficients indicate the statistical significance and the same direction of the effect.

Discussion

The goal of this paper was to examine how three aspects of digital inequality - digital access, capability, and outcome divide - were influencing synchronous online teaching among mainstream schoolteachers in Kazakhstan during COVID - 19 school closures. The paper sought to investigate the effect of several factors. They were urban or rural location, the speed and steadiness of the

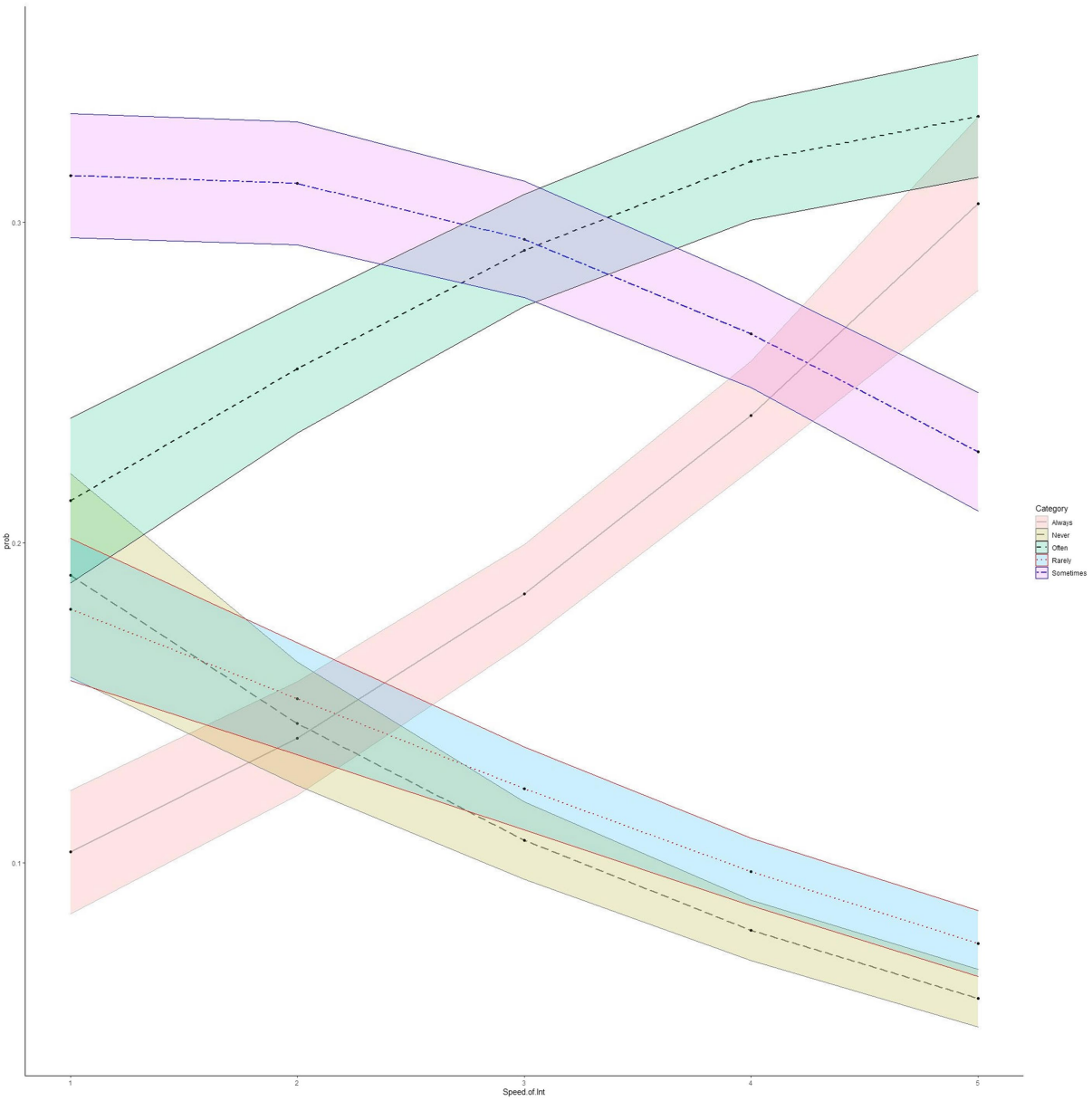

FIGURE 1
Predicted probabilities of the effect of the Internet speed on the use of ICT video tools.

internet connection, the availability of ICT at home and at school, and teacher characteristics such as age, qualification and work experience. This study reportedly found that socio-demographic differences exacerbated the digital divide in synchronous teaching over MS Teams, Zoom, and alike. Yet some of the results in this paper were unexpected.

Digital access

In terms of access to digital technologies and the internet to engage in synchronous online teaching, the availability of school devices and the speed of the internet were found to be significant factors that predicted teachers` remote teaching experiences. In other words, teachers who had access to computers at schools and better internet were likely to use digital tools for synchronous online instruction more often when compared to those who did not have such physical access to ICT. This finding is in line with conclusions in literature that the digital divide due to the lack of ICT access remains a major problem in many parts of the world (Van Dijk, 2006; van Deursen and van Dijk, 2014; Pierce, 2018).

Interestingly, the availability of computers at school rather than at home predicted a higher engagement of teachers in

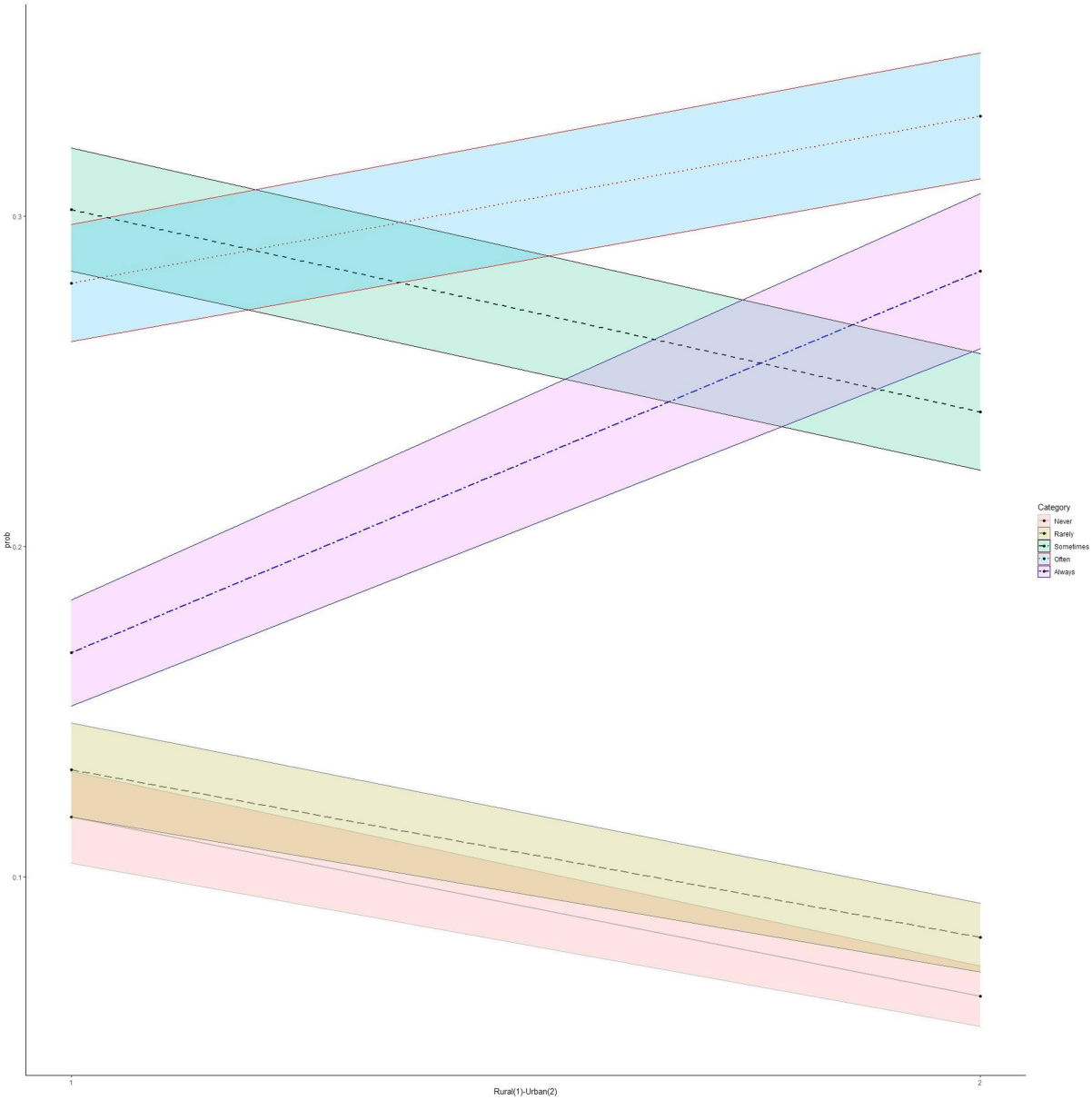

FIGURE 2
Predicted probabilities of the effect of rural -urban locality on the use of ICT video tools.

synchronous online teaching. In Kazakhstan, even though schools were closed for students during the pandemic, teachers could access the school facilities and work from their classrooms following health safety measures. Another explanation for this finding might be that teachers working from home might not have been able to have a computer for their personal use only, needing to share their home devices with other family members. Thus, the availability of a computer that a teacher could use exclusively for their teaching, at school or provided by the school to be used at home, is an important factor in closing the digital divide.

In line with the previous studies (Bagchi, 2005; Hosszu and Rughinis, 2020), our results confirm the difference between rural and urban teachers in the use of ICT tools for synchronous teaching. Nonetheless, a surprising finding is the absence of statistical significance between the locality and speed of the internet. In Kazakhstan, internet coverage in rural settlements does not reach every household, but it does reach key institutions such as local municipal quarters, schools and hospitals (Aliyeva and Kovyazina, 2021). The result shows that the digital access divide may persist in the country, putting teachers in rural areas at a disadvantage.

Alternatively, these results can be related to the phenomena of social desirability bias (SDB) in survey responses (Edwards, 1957; Crowne and Marlowe, 1960; Phillips and Clancy, 1972) when

respondents tend to give answers that show them in favorable light. Thus, teachers may not feel confident about judging the internet quality and restrained from criticizing it openly. This is particularly relevant for sensitive questions about attitude and behavior (Krumpal, 2013). Although to date there is only one attempt at measuring SDB in survey responses in the educational context of Kazakhstan (Nurumov et al., 2022), some surprising findings of OECD's international large-scale surveys and assessments of TALIS and PISA (OECD, 2019, 2020a,b) may support the cautious interpretation of the results in this article regarding the quality of the internet connection keeping in mind potential presence of high SDB in responses.

Digital capability

To examine how the digital capability divide influenced teacher engagement in synchronous online teaching and learning during Covid-19 school closures in Kazakhstan, this paper focused on teachers' personal characteristics such as age and professional qualification and experience. Findings on the impact of teachers' age on their synchronous online teaching practice were in line with those in other studies suggesting that age is the most common indicator resulting in unequal use of digital tools (Enoch and Soker, 2006; Ertl et al., 2020). Older teachers with higher professional rank in Kazakhstan engaged in synchronous online teaching more frequently than their younger counterparts. This suggests that senior teachers tend to adopt recent technologies and have necessary knowledge of using them in remote instruction. It confirms that teachers might be an exception to research findings that lower acceptance and awareness of new technology-led learning are most pronounced among older people compared to younger generations (Olphert and Damodaran, 2013; Wu et al., 2015; Vaportzis et al., 2017;). We initially expected that those teachers who are young in age yet have lower professional rank might be more exposed to a digital teaching environment and use synchronous modes of teaching more frequently than their older counterparts who might find online teaching demanding. Given the prevalence of the older age group among teachers who hold a higher professional rank in our study, suggesting the professional seniority of a teacher, it was a surprise that teachers with longer work experience reported higher engagement in synchronous online teaching than their younger and more recently employed colleagues. From the one hand these results confirmed that the professional rank of teachers in Kazakhstan is associated with their digital capability. From the other, teacher responses may be contaminated by socially desirable answers or other response styles. Given a large number of surveys and educational assessments in Kazakhstan, more research is needed in this direction.

The main conclusion emerging in this research about digital skills divide echoed those from other contexts that ICT skills and their use decrease with age and younger teachers apply ICT tools in their teaching more than their older and more experienced colleagues (Van Braak et al., 2004; Inan and Lowther, 2010; Pegler et al., 2010). At the same time, studies have shown that the likelihood of teachers using ICT in teaching increases if teachers are properly trained to do that (Drossel and Eickelmann, 2017; Pongsakdi et al., 2021). This paper did not examine the question of the teachers' professional development in ICT in Kazakhstan. However, TALIS (OECD, 2019) findings on Kazakhstani teachers' ICT training presents some inconclusive results. Even though seven in 10 Kazakhstani teachers reported having "ICT for teaching" as part of their formal education or training, many more Kazakhstani teachers than the OECD average reported a high need for training to use ICT. This suggests the need to assess the effectiveness of the measures taken to improve the digital capabilities of pre-service and in-service teachers in Kazakhstan. Also, ICT training for teachers in the pre-pandemic period appear to have no lasting effect when navigating the shift from traditional to distance teaching. For instance, Azhari and Fajri (2021) found that teachers' knowledge and willingness to use ICTs before COVID-19 cannot be applied directly in the learning during the COVID-19 pandemic because they used to integrate ICT in typical classrooms. In other words, the experiences acquired through the ICT training courses are less likely to lead to the continued use of that digital knowledge and skills while implementing synchronous teaching during COVID-19.

Digital outcomes

A gap in digital access and capabilities leads to a digital outcome divide. The digital outcome divide "underlines inequalities in the benefits gained from the different levels of access and usage of the Internet" (Ragnedda and Kreitem, 2018, p. 8). It leads to different experiences in learning outcomes and purposeful ICT usage (Wei et al., 2011; van Deursen and Helsper, 2015). Furthermore, regarding teachers, inequality in access to digital technologies and the internet limits professional development, technical skills, and knowledge acquisition through the building of social networks (Valadez and Duran, 2007). Teachers' ability to engage in synchronous online instruction using programs such as Zoom and Google Meet is an indicator of the divide in digital outcomes or lack of it thereof.

As data in this research shows, the most limiting factors for teachers in Kazakhstan to benefit from ICT access and usage in teaching are the urban–rural divide, availability of ICT at schools and teachers' age. Thus, it can be argued that the most vulnerable to digital outcomes divide are rural, young and inexperienced teachers at schools that are not properly equipped with ICT technology. It is important to remember that limitations in digital access and capabilities for teachers are likely to affect the effectiveness of remote learning for students. While based on the data in this paper we cannot

draw definite conclusions about how the digital outcomes divide experienced by teachers impacts students, research indicates that in settings with less digital access and capability among teachers, there is a bigger digital outcomes gap for students (Zhao et al., 2022). Thus, expanding digital access and capabilities among teachers would likely improve digital outcomes for students as well.

Conclusion

Kazakhstan was one of the countries that experienced extended school closures due to the COVID-19 pandemic in 2020. The whole education system switched to remote instruction regardless of the teacher preparation to teach online. An international review of remote learning and teaching during the COVID-19 pandemic found that synchronous teaching, which provides better opportunities for interaction, was more prevalent in the Global North countries (Lucas et al., 2020). This paper examined what factors of digital divide influenced synchronous teaching in Kazakhstan, an upper-middle-income country in Central Asia.

This study found that the digital access divide narrows when schools provide teachers with ICT, which they can use for teaching remotely. The difference in synchronous technology use between teachers in rural and urban areas was significant, suggesting the presence of the digital access divide. In terms of digital skills, the single most crucial factor for teachers' capability to engage in synchronous teaching was age. Surprisingly, teachers with higher professional rank were keener to engage in synchronous teaching than their younger counterparts who belong to lower professional rank. In practical terms this means that investment in school ICT infrastructure development is worth wile to diminish digital divide in access. To reduce digital divide in skills, it is relevant to provide younger and less experienced teachers with ICT-related professional development which targets remote teaching specifically. These two steps will contribute to reducing divide in digital outcomes in teaching and learning.

To gain a more nuanced understanding of how teachers experience digital divide in access, skills and outcomes, it would be beneficial for future research to examine this question in the framework of qualitative research design. When extending the inquiry on this topic, including focus on asynchronous modes of teaching and learning would be important. This study was limited in its focus on synchronous teaching only. Research on blending both synchronous and asynchronous teaching modes might bring a more balanced perspective toward diverse remote teaching experiences in schools. Future research exploring both online teaching formats would be essential to mitigate the challenges associated with synchronous and asynchronous teaching and learning, allowing students to engage with what best suits their individual learning conditions and needs.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

AAm: conceptualization, investigation, and writing. KN: conceptualization, investigation, data curation, visualization, writing, and funding acquisition. RK: conceptualization, supervision, and writing – review and editing. AAk and AK: conceptualization, investigation and supervision. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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Modeling the relationship between digital nativity and Smartphone usage in learning English as a foreign language contexts

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Introduction: Despite many studies exploring the application of digital devices in foreign language learning, only some have investigated the influencing mechanisms of digital nativity on Smartphone usage in this increasingly seamless learning environment. This research aims to explore the relationships between college students' digital nativity and their use of Smartphones for English learning.

Methods: The data were collected from 502 undergraduates in mainland China through self-reported questionnaires, namely the Digital Natives Assessment Scale and the Smartphone Use in Learning Foreign Language Scale.

Results and Discussion: The confirmatory factor analysis validated a four-factor measurement model of digital nativity, including "grow up with technology", "comfortable with multitasking", "reliant on graphics for communication" and "thrive on instant gratification and rewards". A second-order measurement construct of favorable Smartphone usage and its first-order adverse effects in foreign language learning were also examined, demonstrating good validity and reliability. Structural equation modeling analysis revealed that students who displayed more attributes of "grow up with technology" and "thrive on instant gratifications and rewards" tended to adopt smartphones positively for English learning. In addition, those who were more familiar with technological assistance might suffer less from the adverse effects of Smartphone usage. However, the preference for immediate responses and feedback could also lead to more adverse effects when using Smartphones for English learning. Besides, "comfortable with multitasking" and "reliant on graphics for communication" didn't have any significant predictive impact on either the favorable functions or the adverse effects of Smartphone usage. Based on the research results, we discuss the theoretical and practical implications.

KEYWORDS

digital nativity, Smartphone usage, structural equation model, English learning, tertiary education

1. Introduction

In the past two decades, the characteristics of digital natives have aroused broad interest in educational academia, probing either the attributes (Prensky, 2001; Helsper and Eynon, 2010; Teo, 2013) or the influencing mechanisms (Chen et al., 2016; Çoklar et al., 2017; Yurdakul, 2018; Wang et al., 2019; Calvo-Ferrer, 2020; Fiedler et al., 2022) of this burgeoning term. A growing body of evidence has accumulated showing the importance of digital nativity for college students learning (Lei, 2009; Tapscott, 2009; Bennett and Maton, 2010; Margaryan et al., 2011). Prensky (2001) suggests that the brain structures of digital natives are different from their predecessors because of their neuroplasticity nature shaped by the frequent interaction with technologies. Bennett and Corrin (2019) noted that digital natives think, behave, and learn differently from digital immigrants. There is no doubt that digital natives demonstrate a tremendous disparity from the digital immigrants in learning styles (Bennett et al., 2008), habits (Zimerman, 2012), and preferences (Helsper and Eynon, 2010) in the technology-rich environment of modern learning. Despite the popularization of this concept, there is a lack of research examining the influence of digital nativity on using Smartphones for English learning, which has been increasingly reliant on the advancement of digital technology.

Growing up in the mobile world, Smartphone has become an indispensable necessity for today's digital natives in their daily communication, entertaining, and learning. Hence, during the past years, foreign language teachers and educators have witnessed the widespread tendency of Smartphone usage to assist language teaching around the world (Lu et al., 2016; Botero et al., 2018; Wan et al., 2018; Andujar, 2020; Chen et al., 2020). Smartphone is deemed a practical and suitable digital device to facilitate foreign language proficiency in this increasing knowledge explosion era. On the one hand, this benefit is highly attributed to the affordability and accessibility of Smartphone and internet connections (Şad et al., 2020; Wrigglesworth, 2020). On the other hand, there is an agreement among language teaching practitioners and researchers that the audiovisual presentation of language learning materials is proven to be more engaging and interactive in helping language learners immersed in an authentic learning environment seamlessly (Kim and Kwon, 2012; Andujar, 2016; Lekawael, 2017; Hwang and Fu, 2018). Just as pointed out by Prensky (2005) in his observation about the ubiquitous power of the cell phone that "cell phones complement the short-burst, casual, multitasking style of today's digital natives." However, there is a lack of empirical investigation on the relationship between digital nativity and Smartphone usage in college students' foreign language learning, even though there exists significant literature in support of digital nativity as an antecedent for online behaviors and proficiency among college students (Chen et al., 2016; Çoklar et al., 2017; Yurdakul, 2018; Wang et al., 2019; Calvo-Ferrer, 2020).

Given the research gaps mentioned above, this study explores how different digital attributes predict both beneficial and detrimental effects of Smartphone usage. Structural equation modeling analysis was used to examine the relationships of digital nativity with favorable Smartphone usage and its adverse impact separately. We postulate that the granular exploration into the predicting effects of digital nativity would enhance our insights into the influencing mechanisms of digital native features as significant antecedents in affecting students' use of Smartphones to learn English.

2. Literature review

2.1. Digital nativity and its effect on learning

Digital nativity is the multi-dimensional construct of psychological characteristics and behavioral tendencies possessed by those fluent in technological practices. Teo (2013) conducted a pioneering empirical study to develop a psychometric scale for the measurement of digital nativity with four attributes, namely "grow up with technology," "comfortable with multitasking," "reliant on graphics for communication," "thrive on instant gratifications and rewards." This scale was further validated in different contexts cross-culturally (Chen et al., 2016; Çoklar et al., 2017; Yurdakul, 2018; Wang et al., 2019; Calvo-Ferrer, 2020) with different ages (Huang et al., 2021). Furthermore, some findings revealed that age does not distinguish digital natives from digital immigrants (Helsper and Eynon, 2010; Zhao and Zhao, 2021).

Previous studies have generally established the relationship between digital nativity and online learning tendencies and behaviors (Chen et al., 2016; Çoklar et al., 2017; Yurdakul, 2018; Wang et al., 2019; Calvo-Ferrer, 2020; Zhao and Zhao, 2021); however, the relational directions among these variables are unclear. To be specific, digital nativity was found to be correlated positively with adaptive online behaviors, such as, online information search strategies and information literacy (Çoklar et al., 2017; Aharony and Gazit, 2019), pre-service teachers' technological pedagogical content knowledge (TPACK; Yurdakul, 2018), teachers' technology adoption (Zhao and Zhao, 2021), and sustainability education outcomes (Fiedler et al., 2022). On the contrary, digital nativity has also been found to be related to maladaptive behaviors, such as distraction of academic motivations (Chen et al., 2016) and technological additions (Wang et al., 2019). Therefore, whether digital nativity has positive or negative effects on people's online behaviors is still blurred. To our knowledge, only two studies have explored the effect of digital nativity on students' English learning but yielded inconsistent results (Calvo-Ferrer, 2020; Wang et al., 2022). Calvo-Ferrer (2020) finds out that in an online gamified learning context, the attribute of "multitasking" negatively predicts students' English vocabulary learning, while "grow up with technology" and "thrive on instant gratifications and rewards" are positively related with students' vocabulary learning outcomes. But "reliant on graphics for communication" is not correlated with their vocabulary learning achievement. Wang et al. (2022) reported that digital

nativity was positively related to students' online self-regulation and English learning engagement. Therefore, despite the importance of digital nativity in understanding students' learning patterns and behaviors in technology-rich environments (Tapscott, 1999; Prensky, 2001; Teo, 2013; Tran et al., 2020; Huang et al., 2021; Fiedler et al., 2022), there is still a shortage of studies examining the effects of digital native attributes on students' English learning practices and attitudes in digital environments (Calvo-Ferrer, 2020).

2.2. Smartphone usage in foreign language learning

Smartphones have many advantages for university students' foreign language learning. On the one hand, the portability and multi-functions of Smartphones have dramatically contributed to their dominance in mobile-assisted language learning (MALL). Besides, communicative function based on advanced technology in automated corrective feedback generation and augmented reality enhanced the interactive efficiency (Wrigglesworth, 2020). The multimodal display (Pachler et al., 2010) and the gamification features can easily arouse the enthusiasm of application users, stimulating their innate motivation for language learning (Calvo-Ferrer, 2015) and turning the monotonous drills of language structure exercises into an engaging and appealing experience (Purgina et al., 2020).

Despite the prevalence of Smartphone usage, with some studies revealing the positive effects on foreign langue learning, there exist a discrepancy between learners' perceptions about and the actual use of Smartphone apps in their English learning (Şad et al., 2020; Metruk, 2022). For example, potential learning distraction (Metruk, 2020), unethical cheating in exams (Ugur and Koç, 2015), and insufficient readiness for technology adoption among teachers (Dashtestani, 2013) are the three significant drawbacks of incorporating mobile technology into classrooms (Metruk, 2020). Other obvious problems are the physical features of Smartphones in terms of the small screen size (Dashtestani, 2013; Arinder, 2020), unstable internet access, and financial and technological challenges (Burston, 2014; Ekinci and Ekinci, 2017) as well as the lack of guidance for students using Smartphones productively (Abdullah et al., 2019).

To comprehensively examine first-year students' views toward Smartphone usage in English learning, Şad et al. (2020) designed a scale to investigate both the pros and cons of Smartphones in modern youth lives concerning their foreign language learning. The scale consists of four dimensions, inspecting both the positive and negative influence of Smartphones on college students' English learning. The four dimensions are "General Contribution," "Reading and Writing," "Speaking and Listening" and "negative effects" This instrument provides a comprehensive tool to inspect college students' Smartphone practices in their English learning.

Based on the above analysis, we argue that the first three dimensions of Smartphone usage may converge on a higher-order construct, namely favorable Smartphone usage. The last dimension of adverse effects may form a distinct factor. In addition, the positive and negative effects of Smartphones are conceptually different constructs, which formulate innately contradictory relationships (Şad et al., 2020; Metruk, 2022). The proposed second-order factor has some merits, such as parsimony, the avoidance of bandwidth-fidelity dilemma, and collinearity reduction (Sarstedt et al., 2019). Therefore, it is sensible to distinguish the favorable effects from the adverse effects of Smartphone usage while examining their predictive power on digital nativity.

2.3. The relationship between digital nativity and Smartphone use

Some researchers (e.g., Hwang and Fu, 2018) have argued that more attention should be given to the affective or psychological states of learners in mobile-assisted language learning processes. Digital nativity is a psychometric attribute with different levels among individuals than a generational trait (Teo, 2013). Hence, it is illuminating to explore the relationship between the psychometric properties of digital nativity and students' Smartphone usage in English learning.

First, Teo (2016) summarized that digital natives were more efficacious in using state-of-the-art technologies. Thongsri et al. (2020) discovered that Chinese students' computer self-efficacy positively affected college students' scores and satisfaction in using mobile phone applications to improve their English vocabulary. Their findings indicate that those confident in their computer capability are more likely to explore the advanced functions of mobile devices. In addition, Şad et al. (2020) discovered that the more time college students spent online, the more frequently they displayed using Smartphones to do listening and speaking activities and suffered more adverse effects from Smartphone usage. Regarding second language vocabulary acquisition, "grow up with technology" positively predicated both short-term and long-term gains (Calvo-Ferrer, 2020). Therefore, it is reasonable to presume that the attribute of "grow up with technology" positively influences "favorable Smartphone usage" as well as "adverse effects."

Second, previous studies show that the relationship between multitasking and learning is still blurred. For example, research proved that multitasking negatively influences online learning (Burak, 2012). In addition, multitasking is a significant distraction for learning with mobile phones (Chen and Yan, 2016; Klimova, 2019). In other investigations, multitasking is negatively associated with learning achievement (Junco and Cotton, 2012; Ravizza et al., 2014). Specifically, multitasking negatively predicted students' English vocabulary acquisition in both short-term and long-term retention (Calvo-Ferrer, 2020). But, in one empirical research, there was no relationship between students' rate of correct answers after watching video material and using mobile phones for texting during the watching process (Lawson, 2013). In addition,

"comfortable with multitasking" cannot predict Smartphone addiction significantly (Wang et al., 2019). Because of the mixed results of previous findings, more empirical evidence is needed to explore the specific effects of multitasking on learning. Then, we propose that "comfortable with multitasking" negatively influences "favorable Smartphone usage." But "comfortable with multitasking" positively influences the "adverse effects."

Prensky (2001) believes that "reliant on graphics" is an adaptive feature for digital natives because of the neuroplasticity in their brains. What's more, Lowe and Pramono (2006) found that pictures and annotations are facilitating factors for understanding complex and dynamic information. Besides, other empirical evidence reveals that high graphic and video annotation usage leads to significant high achievement and retention in foreign language vocabulary learning, indicating the effectiveness of graphics and videos in vocabulary acquisition (Gürkan, 2018). Nevertheless, "reliant on graphics" is reported to positively predict all four types of information technology addiction (Wang et al., 2019). Consequently, we postulate that the effects of "reliant on graphics for communication" are very complex. "Reliant on graphics for communication" may positively affect "favorable Smartphone usage." It may also positively influence "adverse effects" in learning English.

Previous survey results reveal that "thrive on instant gratifications and rewards" is associated significantly with Internet gaming disorder and Smartphone addiction, indicating this dimension's negative effect on learning. Additionally, Chen et al. (2016) presumed that thriving on instant gratification and rewards would interfere with students' academic learning motivation, which negatively affects students' school decisions. According to Bembenutty and Karabenick (2013), delay of gratification, as the opposite concept of instant gratification, is positively associated with students' self-regulation, which is a significant predictor of students' academic achievements (Zheng and Li, 2016). Despite the adverse effects, "thrive on instant gratifications and rewards" was discovered to influence students' short-term English vocabulary acquisition, while having no predictive impact on the long-term gains (Calvo-Ferrer, 2020). Therefore, we hypothesize that "thrive on instant gratifications" negatively influences "favorable Smartphone usage." However, "thrive on instant gratifications" positively affects "adverse effects" in learning English.

2.4. The present study and research questions

With the prominent role of digital nativity in shaping young adults' daily behaviors increasingly recognized in the literature (Prensky, 2001; Teo, 2013; Çoklar et al., 2017; Wang et al., 2019), the relevant exploration can be further extended in more aspects. First, there is scarce research exploring effects of digital nativity on students' learning behaviors in the technological environment. It is also essential to examine the separate impact of digital nativity on students' use of technology (Prensky, 2001). That's because most previous studies have explored digital nativity from a holistic perspective (Çoklar et al., 2017; Yurdakul, 2018; Fiedler et al., 2022), which can not reveal the precise influencing mechanisms of individual digital characteristics. Therefore, it is important to take each factor as distinct psychological characteristics or behavioral tendencies (Wang et al., 2019).

On the other hand, the influence of different attributes may not display the same influencing pattern. Thus, it is necessary to investigate the effects of individual digital native characteristics so that a clear directional influence of each predictor can be manifested. Second, although the use of Smartphones in foreign language learning has aroused increasing attention among scholars (Nami, 2020; Zou et al., 2022), there has been comparatively little attention to the use of Smartphones from the perspective of digital nativity as antecedents. Third, unlike the Digital Natives Assessment Scale, which has been validated by many studies in China (Teo, 2016; Huang et al., 2021; Zhao and Zhao, 2021) and western countries (Çoklar et al., 2017; Yurdakul, 2018; Calvo-Ferrer, 2020; Fiedler et al., 2022), the "Smartphone Use in Learning Foreign Language Scale" has primarily been designed in Turkish environment. Consequently, the validity and reliability of this scale need to be examined with more empirical data in a broader cultural context.

Based on the literature mentioned above, it is critical to specify the multidimensions of both digital natives and Smartphone use in English learning context and explore the complex associations between four attributes of digital nativity and favorable and adverse effects of Smartphone use. This study aims at answering the following research questions (RQs):

1. What is the factorial structure of digital natives for Chinese EFL learners?
2. What is the factorial structure of Smartphone usage in learning a foreign language?
3. To what extent does digital nativity predict Smartphone usage.

3. Materials and methods

3.1. Participants

A total of 502 valid responses from first-year undergraduates were collected in mainland China voluntarily. There were 42.4% males ($n = 213$) and 57.6% females ($n = 289$). The average age was 19 ($SD = 0.89$), ranging from 17 to 24. The respondents claimed to have used Smartphones for around 80 years ($SD = 3.00$), indicating their familiarity with Smartphone usage. The participants reported hometowns were of different categories in terms of locations (39.8% rural or small-town areas, 60.2% urban areas). The participants were divided into four major categories, among which 49.8% were from science, 24.7% were from Arts, 20.9% were from Business or Management, and 4.6% were from foreign languages. On average, students' self-assessed family financial status was 3.72 ($SD = 1.06$), with 1 representing extremely poor and 7 indicating extremely rich. The average score means these respondents were, on average, from medium-ranking economy families.

3.2. Measures

3.2.1. Chinese digital natives assessment scale

Chinese Digital Natives Assessment Scale (Teo, 2016) was used to measure the attributes of college students' digital nativity. The questionnaire has both Chinese and English versions. This study used the Chinese version of the questionnaire consisting of 21 items, measuring four aspects of the digital characteristics of modern college students, namely "Grow up with technology" (5 items, e.g., I use the Internet every day), "Comfortable with multitasking" (6 items, e.g., I am able to surf the Internet and perform another activity comfortably), "Reliant on graphics for communication" (5 items, e.g., I use pictures more than words when I wish to explain something) and "Thrive on instant gratifications and rewards" (5 items, e.g., I expect quick access to information when I need it). All items were rated on a seven-point Likert scale, ranging from 1 (not at all true of me) to 7 (very true of me). The Cronbach's α for each factor in Teo's research (2016) was: 0.89, 0.92, 0.88, 0.87. The model fits of CFA were: $\chi 2/df = 2.94$; CFI = 0.94; TLI = 0.92; SRMR = 0.04; RMSEA = 0.07, indicating the reliability and validity of the instrument.

3.2.2. Smartphone use in learning foreign language scale

This research used Smartphone Use in Learning Foreign Language Scale (Şad et al., 2020) to elicit Chinese college students' use of Smartphones for English learning in general, thus it does no focus on any specific English skill. This questionnaire is composed of 21 items measuring both favorable English learning behaviors on the Smartphone and the negative influence of Smartphones on English learning. The seven-point Likert scale includes four factors, which are "General Contribution" (6 items, e.g., I do activities on English learning websites on my Smartphone); "Reading and Writing" (5 items, e.g., "I blog in English through my Smartphone"); "Listening and Speaking" (4 items, e.g., "I watch videos in English on my Smartphone"); and "Adverse Effects" (6 items, e.g., "I have difficulty in focusing on my English classes because of my Smartphone"). In the research of Şad et al. (2020), exploratory factor analysis was conducted, and four factors were extracted, accounting for about 55% of the total variance. The factor loading ranged from 0.52 to 0.84. The Cronbach α coefficients were 0.82, 0.81, 0.79, and 0.68. No confirmatory factor analysis was used to test the factorial structure. However, based on our examination of item meanings, the first three factors describe the active usage of Smartphones in facilitating students' English learning. Therefore, a second-order measurement model was tested (Sarstedt et al., 2019), including the first three factors, which means we tested the favorable usage and adverse effects separately. Given the differences in respondents' English proficiency, the questionnaire was translated into Chinese by a college English teacher familiar with this research and proved by a professor in applied linguistics (Brislin, 1970). Since the two scales were all adapted from previous literature, the content validity of the instruments was guaranteed (Straub et al., 2004).

3.3. Procedures and analyses

Before the formal data collection, a pilot test was conducted to examine the validity of the measurement. We asked six students in the target test group to complete the questionnaire. Based on the comments on the wording, clarity, and comprehensibility of the questionnaire, the researchers reworded some items. Thereafter the anonymous online survey was distributed to undergraduate students from eight universities in six different provinces (i.e., Hebei, Jilin, Liaoning, Shandong, Shanghai, and Guangdong) in mainland China. All the respondents were informed that the data were only used for research purposes. For most participants, it took 3 to 8 min to answer all the questions in Chinese.

The data were analyzed by using SPSS17.5 and AMOS 25.0. Confirmatory factor analysis (CFA) was adopted to examine the construct validity of the two scales (Jackson et al., 2009). Informed by the literature, we investigated a four-factor correlated structure of digital nativity. A second-order factor of favorable Smartphone usage and a first-order factor of adverse effects were also tested. Then the internal consistency (Cronbach alpha, AVE, and CR) was examined to evaluate the reliability of each factor.

Pearson product–moment correlations were conducted as the basis for further structural relationship building. Structural equation modeling (SEM) was then utilized to investigate the path relationships among different antecedents (digital nativity) and outcome variables (Smartphone usage). Fit indices such as the chi-square/*df* ratio, Comparative Fit Index (CFI), the Tucker-Lewis Index (TLI), the Root Mean Square Error of Approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR) were referred to as indicators for the hypothesized model. While the chi-square test is a popular way to test model fit, several limitations exist. For example, the chi-square statistic is sensitive to sample size, so it may reject the research model when the number of samples is large (Bentler and Bonett, 1980). In this research, the sample size is 502, which is relatively large. Therefore, χ2/df is an alternative to chi-square to test the model fit (Wheaton et al., 1977). Usually, indices larger than 0.90 for the CFI and TLI are acceptable; a value smaller than or equal to 0.05 of RMSEA and a number less than 0.08 of SRMR represented acceptable fit indices (Hu and Bentler, 1999; Schumacker and Lomax, 2010; Byrne, 2011).

4. Results

4.1. Validating the factorial structure of digital natives

We conducted multivariate normal distribution test first. The results of the skewness and kurtosis value indicated the normal distribution of the data. To test the validity and reliability of the digital nativity instrument, maximum likelihood (ML) estimation was adopted as the CFA calculation method. The measurement model fits were as follows: $\chi 2\ (183) = 602.64$; $\chi 2\ /df = 3.29$; $p < 0.001$; CFI = 0.90; TLI = 0.88; RMSEA (90% confidence interval) = 0.068

[0.062, 0.074]; SRMR = 0.060. The overall model fits values were marginally acceptable. An inspection of the standardized estimates of each item on individual factors revealed that one item loading in the "comfortable with multitasking" was below 0.45. We deleted this items which is a common practice when the factor loading of a specific item is lower than 0.5 (Comrey and Lee, 2013). Hence, this item was deleted. Subsequently, a re-run of CFA for the following 20 items generated a better model fit: $\chi 2$ (164) = 490.83; $\chi 2/df = 2.99$; $p < 0.001$; CFI = 0.92; TLI = 0.90; RMSEA (90% confidence interval) =0.063[0.057, 0.070]; SRMR = 0.056. Figure 1 presents the modified CFA measurement structure.

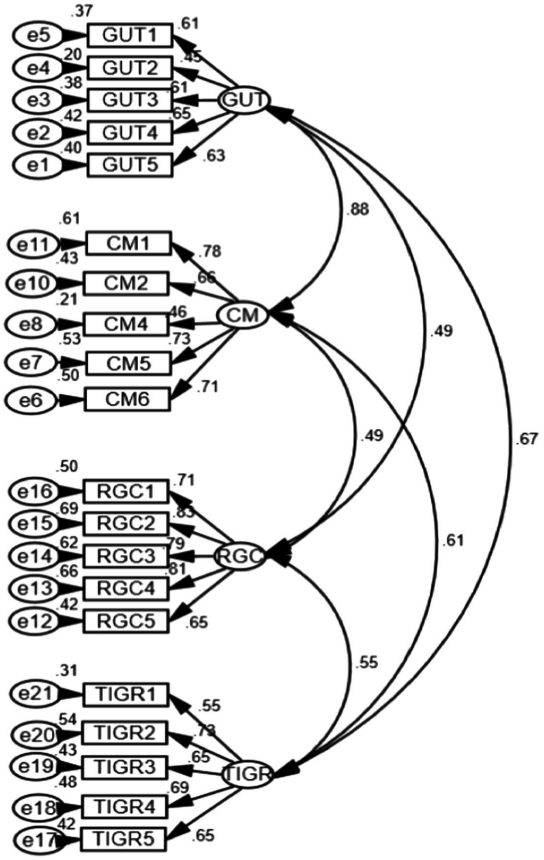

FIGURE 1
The confirmatory factor analysis result of C-DNAS (GUT, grow up with technology; CM, comfortable with multitasking; RGC, reliant on graphics for communication; TIGR, thrive on instant gratification and rewards).

As shown in Table 1, the factor loading of each item is above 0.45, with the Average Variance Extracted (AVE) values between 0.35 and 0.58, which exceeds or close to the acceptable threshold of 0.36–0.50 (Fornell and Larcker, 1981). In addition, the Composite Reliability (CR) value of each factor is from 0.72 to 0.87, which is above the cut-off value of 0.70 (Nunnally, 1978; Fornell and Larcker, 1981). Besides, the Cronbach alpha values for each sub-factor ranged from 0.71 to 0.87, with the overall Cronbach alpha value being 0.90, demonstrating excellent internal consistency of the items (Table 2). Therefore, the revised measuring model of digital nativity displayed relatively good validity and reliability in this research context.

4.2. Validating the factorial structure of Smartphone use

Informed by the literature review, we tested the favorable and adverse effects of Smartphone use in two different models. First, a second-order measurement construct of the favorable usage of Smartphone was examined, generating unacceptable model fit indices: $\chi 2$ (87) =914.40; $\chi 2/df = 10.51$; $p < 0.001$; CFI = 0.82; TLI = 0.79; RMSEA (90% confidence interval) =0.138 [0.130, 0.146]; SRMR = 0.10. By examining the modification indices, we noticed that the error variance of one item had a strong correlation with the error of one latent variable. This item describes learners' practice of using Smartphones when talking with foreigners on social media. It correlates with "General contribution" which describes students' use of apps, websites, and tutorials on their Smartphones to practice their vocabulary, listening, and pronunciation. But to make a correlation between the error of an observable variable and a latent variable violates the basic assumptions of structural equation modeling (Kline, 2016). Therefore, this item was deleted. Besides, according to the MI values, we built some correlations between the errors within the same factors. Thus, the revised model fit indices were: $\chi 2$ (71) =351.15; $\chi 2/df = 4.95$; $p < 0.001$; CFI = 0.93; TLI = 0.92; RMSEA (90% confidence interval) =0.089[0.080, 0.098]; SRMR = 0.072. These fit indices were relatively adequate. Consequently, the model was accepted, as shown in Figure 2. The factor loading of each item for favorable Smartphone usage ranged from 0.62 to 0.87, all above 0.5. The AVE values all surpassed the cut-off value of 0.5, and the CR values ranged from 0.80 to 0.90, designating an excellent

TABLE 1 The reliability of chinese digital natives assessment scale.

Factors and items	Mean	S.D.	AVE	CR	Alpha
Grow up with technology (GUT)	5.59	1.06	0.35	0.72	0.71
Comfortable with multitasking (CM)	5.10	1.36	0.56	0.80	0.80
Reliant on graphics for communication (RGC)	4.56	1.41	0.58	0.87	0.87
Thrive on instant gratifications and rewards (TIGR)	5.25	1.19	0.43	0.79	0.79

AVE, average variance extracted; CR, composite reliability.

TABLE 2 The CFA of Smartphone use in learning foreign language scale (SULFLS; *N*=502).

Factors and items	Mean	SD	AVE	CR	Alpha
Favorable Smartphone usage	4.22	1.22	0.61	0.82	0.91
General contribution (GC)	4.86	1.41	0.51	0.86	0.88
Reading and writing (RW)	2.89	1.59	0.64	0.90	0.91
Listening and speaking (LS)	4.91	1.50	0.58	0.80	0.80
Adverse effects (AE)	3.61	1.36	0.51	0.83	0.84

AVE, average of variance extracted; CR, composite reliability; Alpha, cronbach alpha.

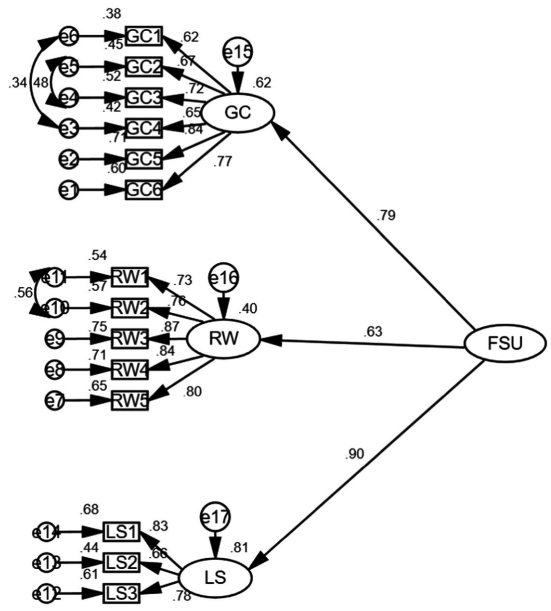

FIGURE 2
The second-order factor result of the favorable Smartphone usage scale (Note: FSU, favorable Smartphone usage; GC, general contribution; RW, reading and writing; LS, listening and speaking).

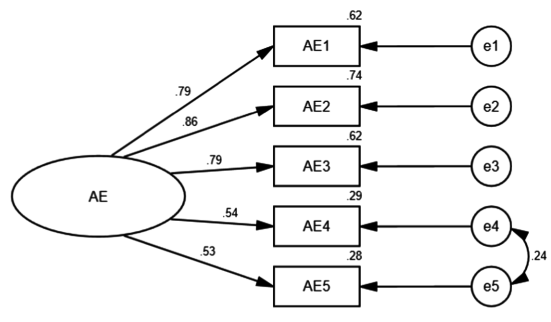

FIGURE 3
Confirmatory factor analysis of adverse effects. (AE, adverse effects).

convergent validity. What's more, the total Cronbach alpha value of the scale was 0.91, with the reliability values of each sub-factor between 0.80 and 0.91, indicating good internal consistency. Therefore, the revised second-order construct of the favorable Smartphone usage scale is valid and reliable in Chinese contexts.

TABLE 3 The correlations among C-DNAS and SULFLS.

Factors	GC	RW	LS	FSU	AE
GUT	0.22**	−0.06	0.30**	0.19**	0.07
CM	0.19**	0.07	0.29**	0.23**	0.03
RGC	0.09*	0.11*	0.20**	0.19**	0.17**
TIGR	0.25**	0.04	0.31**	0.25**	0.26**

**Correlation is significant at the 0.01 level. *Correlation is significant at the 0.05 level. GUT, grow up with technology; CM, comfortable with multitasking; RGC, reliant on graphics for communication; TIGR, thrive on instant gratifications and rewards; GC, general contribution; RW, reading and writing; LS, listening and speaking; FSU, favorable Smartphone Usage; AE, adverse effects.

Then we examined the adverse effects of Smartphone use on the Learning Foreign Language Scale. CFA results showed unacceptable indices: $\chi 2$ (9) =102.46; $\chi 2/df = 11.39$; $p < 0.001$; CFI = 0.92; TLI = 0.86; RMSEA (90% confidence interval) =0.144[0.120, 0.170]; SRMR = 0.07. According to the MI values, we built correlations between the errors of two items. Besides, the factor loading of one item was below 0.45. Hence this item was also deleted. Then the CFA result indicated the following fit indices: $\chi 2(4) = 8.88$; $\chi 2/df = 2.22$; $p = 0.064$ ($p > 0.05$), CFI = 0.99; TLI = 0.99; RMSEA (90% confidence interval) =0.049 [0.000, 0.094]; SRMR = 0.02. Then the revised adverse effects model was accepted, as shown in Figure 3. The factor loading of each item for adverse effects ranged from 0.53 to 0.86, all above 0.5. The AVE was 0.51, and the CR value was 0.83, signaling an excellent convergent validity. The total Cronbach alpha value of the scale was 0.84, showing good internal consistency.

4.3. Predictive effects of digital nativity and Smartphone usage

Table 3 shows that four factors of C-DNAS were all significantly related to the second-order factor of favorable Smartphone usage. But "grow up with technology" and "comfortable with multitasking" are not significantly correlated with adverse effects.

First, a structural equation modeling was conducted to examine how the four antecedents of digital nativity generated positive

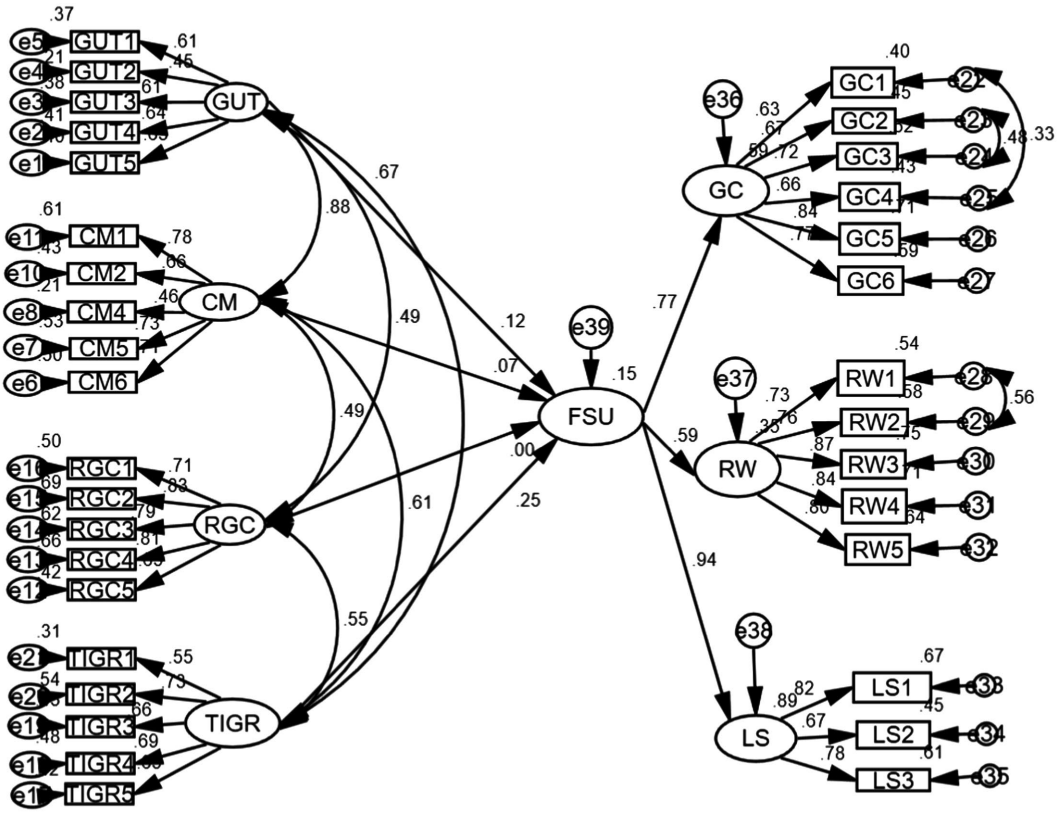

FIGURE 4
The SEM results of digital nativity and favorable Smartphone usage.

effects on Smartphone usage of English learning. The model fit indices were acceptable, which were: $\chi 2\ (511) = 1336.86$; $\chi 2/df = 2.62$; $p < 0.01$; CFI = 0.90; TLI = 0.89; RMSEA (90% confidence interval) = 0.057 [0.053, 0.061]; SRMR = 0.071. As shown in Figure 4, "grow up with technology" and "thrive on instant gratifications and rewards" significantly predict favorable Smartphone usage positively, with path coefficients separately as 0.12 and 0.25.

The structural equation modeling indices between digital nativity and adverse effects are: $\chi 2\ (264) = 698.57$; $\chi 2/df = 2.65$; CFI = 0.91; TLI = 0.90; RMSEA (90% confidence interval) = 0.057[0.052, 0.063]; SRMR = 0.06; $p < 0.00$. In this model, as shown in Figure 5, "grow up with technology" negatively predicts the adverse effects to a significant level ($\beta = -0.31$, $p < 0.01$), and "thrive on instant gratifications and rewards" positively explains the variations of adverse effects ($\beta = 0.48$, $p < 0.01$). However, in both models, "comfortable with multitasking" and "reliant on graphics" fail to predict either the favorable Smartphone usage or the adverse effects, because none of the path coefficients is significant.

5. Discussion

The study aimed to examine the predictive effects of digital natives on Smartphone use in Chinese EFL contexts. Digital nativity was found to be a four-factor structure, including "grow up with technology," "comfortable with multitasking," "reliant on graphics for communication" and "thrive on instant gratifications and rewards," in line with the results found in other learning contexts (Chen et al., 2016; Teo, 2016; Çoklar et al., 2017; Yurdakul, 2018; Wang et al., 2019; Calvo-Ferrer, 2020; Huang et al., 2021; Zhao and Zhao, 2021). These factors resonated Prensky (2001) summary for the typical features of digital natives and supported the contention that digital nativity is a psychometric property instead of characteristics defined by age discrepancy (Teo, 2013; Huang et al., 2021; Zhao and Zhao, 2021). As was noted by Teo (2013), this result shows the degree to which the participants perceive themselves as technological acquaintances, with higher scores designating more tendency toward digital nativity. The applicability of the scale as an effective instrument to examine an individual's digital nativity was also tested.

One interesting result is the second-order construct of favorable Smartphone usage, with the three positive dimensions ("general contribution," "reading and writing," "listening and speaking") loaded on a higher factor, named favorable Smartphone usage. Our findings revealed that the three advantageous factors converged on one inclusive construct, enclosing the active use of Smartphones as effective and beneficial in English learning. It coincides with Şad et al. (2020) research results, in which both positive and negative

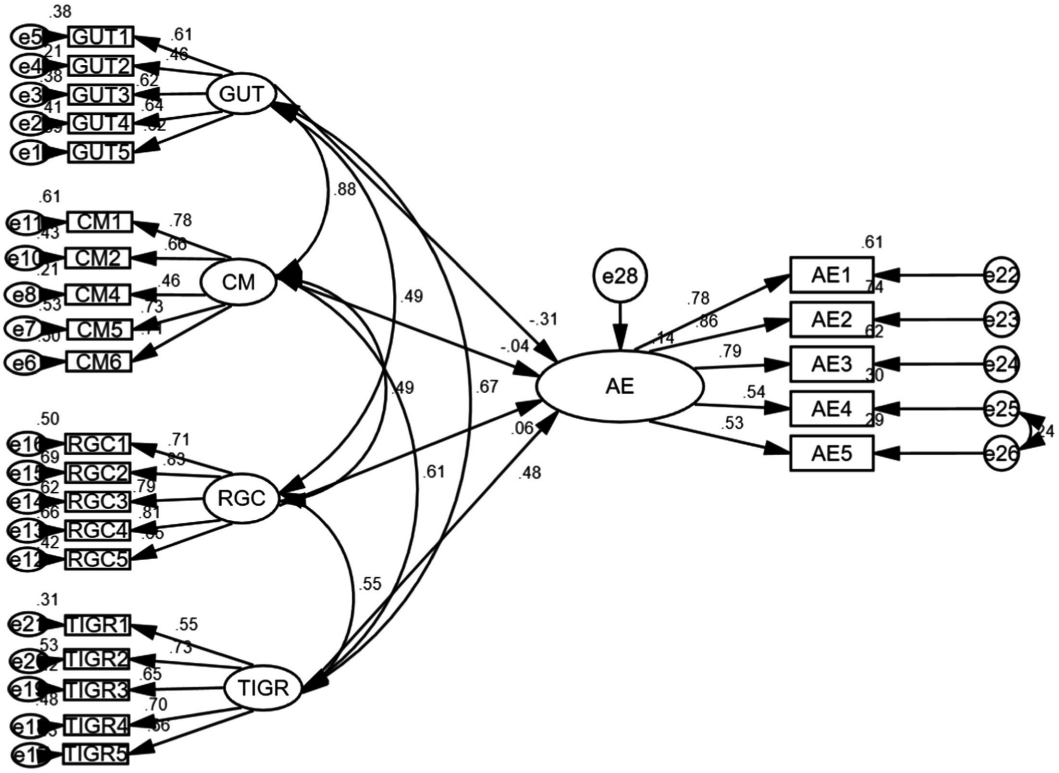

FIGURE 5
The path between digital nativity and adverse effects of Smartphone usage.

effects of Smartphone use were examined. However, students showed a less tendency to use Smartphones for their reading and writing skills, which might be caused by the small screen size (Şad et al., 2020) and inconvenience of typing on the delicate gadget. Therefore, the physical feature of Smartphones might be the reason for the participants to conduct less reading or writing activities. Another possible reason is the relative negligence of English writing in university education. Gao (2007) pointed out that although writing plays an integral role in the four basic language skills, it has long been neglected in Chinese universities. In addition, the adverse effects of five items formed a distinct factor, including the entertaining nature and distractive activities while using Smartphones (Metruk, 2022). Besides, the easy access to information with the help of Smartphone also plays a harmful effect on students' deep cognition. The result is similar to the previous argument of Şad et al. (2020) that students use their Smartphones to improve their English skills generally. Still, the easy access to English language content *via* Smartphones generates negative effects on their deep thinking and cognition. Therefore, while recognizing the benefits of Smartphone usage to improve English learning, learners should also be cautious for the potential harms and detriments of Smartphones usage. Generally speaking, it is essential to explore both positive and negative impacts of Smartphone use for educational purposes (Baran, 2014).

Another significant contribution of this study is the examination of the comprehensive path impacts of four digital native attributes on the favorable use and the adverse effects. The path evaluation results showed a significant positive predicting effect from "grow up with technology" to favorable use of Smartphones in English learning. As Teo (2016) found, digital natives who grew up with the advancement of technology considered themselves skillful technologically, and those who possessed more characteristics of digital natives used technology longer. It is reasonable to posit that those who show more attributes of digital nativity tend to be more adept in technology usage since they have more technological experience with more substantial technology confidence. As previous researchers claimed (Frand, 2000; Oblinger and Oblinger, 2005), digital natives prone to possess better cognitive capacities. Hence, students who have access to technology frequently are more likely to adopt appropriate technological tools according to the nature of different learning tasks and value the usefulness of mobile technology. In other words, college students with more experience with technology access might also report that they use Smartphones to benefit English learning. Therefore, it is reasonable to argue that college students with sufficient technological experience benefit more from using Smartphones in their English learning processes.

Our study reported that "grow up with technology" negatively influenced the adverse effects. This might be attributed to the claim by Prensky (2001) that human brains may grow and change in response to environmental stimulation. The brain structures of

digital natives might display neuroplasticity and malleability as an adaptation to the increasingly digitalized world (Prensky, 2001). As such, digital natives growing up with technological advancement command a repertoire of facilitating strategies (Tapscott,1999; Prensky, 2001) for their English learning with mobile assistance and develop anti-distraction (antijamming) mechanisms to minimize the adverse effects. For example, Wang et al. (2019) reported that "grow up with technology" have no significant predicting impact on Smartphone addiction. Their study revealed a negative path coefficient between this attribute of digital nativity and Smartphone addiction, although insignificantly. What's more, a similar research result showed that none of the digital nativity attributes could be used as a predictor for students' disengagement with the educational system (Calvo-Ferrer, 2020). Hence, the "grow up with technology" feature can be taken as a beneficial factor (Tapscott, 1999; Prensky, 2001) in alleviating language learners' sufferings from the adverse effects of Smartphone usage. It is taken as an affirmative feature (Aharony and Gazit, 2019), positively contributing to the favorable use and negatively affecting the adverse effects.

However, "thrive on instant gratifications and rewards" displayed a much more mixed influence on Smartphone usage, which has a significant predicting effect on both favorable and adverse use of Smartphones. On the one hand, the convenience of Smartphones can readily satisfy learners' instant needs and provide immediate feedback (Kukulska-Hulme and Viberg, 2018; Şad et al., 2020). Hence digital learners who thrive on instant gratifications have a strong tendency to adopt Smartphones as a valuable tool to English practice positively. This positive aspect is in line with Jiang and Zhang (2020) findings that English learners with proper guidance can improve communication efficiency and writing skills by using mobile devices. Consequently, mobile devices have become an ideal tool for fulfilling the needs of modern digital learners, which explains the positive path from "thrive on instant gratifications and rewards" to positive Smartphone usage. On the other hand, concerning the higher predicting role "thrive on instant gratifications and rewards" played in adverse use of Smartphones, a preference for quick responses by using mobile phones may lead up to this adverse effect. According to the research result of Chen et al. (2016), the preference for quick access to information may distract students from their academic engagement and interfere with students' academic decisions. Therefore, the priority of efficient need satisfaction may incur the sacrifice of long-term mastery of English among today's digital natives and lead to superficial achievements in the short-term (Calvo-Ferrer).

We also found the insignificant predicting effects between multitasking and Smartphone usage in either positive or negative ways. The result echoes relevant research findings, showing that multitasking does not significantly predict either Smartphone addiction (Wang et al., 2019), technological disengagement (Calvo-Ferrer, 2020), or leisure decisions in a school-leisure conflicting environment (Chen et al., 2016). However, this finding contradicts Burak (2012) result that students' multitasking is significantly related to lower online learning outcomes. One possible reason might be that Smartphone usage for English learning does not involve multitasking processes. As noted by Teo (2013), the digital natives' assessment did not distinguish between various digital environments, such as computers, video games, Smartphones, etc. Smartphones usually do not allow the operation of many tasks within a small gadget. The absence of multitasking operations may be the reason for insignificant predicting effects. However, the robustness of this research finding is still open for further tests. More empirical research is needed to test the influencing mechanism of multitasking on digital natives learning behaviors with high-tech devices.

Besides, the characteristics of "reliant on graphics for communication" did not predict students' adaptive usage of Smartphones or maladaptive functions. This outcome coincides with the research results that the preference for graphics in communication cannot statistically predict either the short-term or the long-term vocabulary retention and disengagement of the education system in a game-based online environment (Calvo-Ferrer, 2020). But it contradicts the evidence in previous research, which found this feature of the digital nativity to be a significant antecedent for Smartphone addiction (Wang et al., 2019). This may be due to the nature of language learning. Listening, speaking, reading, and writing are usually considered core skills for language learning. However, none of the learning processes was directly associated with using pictures or graphics. Graphics may facilitate learners' comprehension of abstract knowledge or the absorption of content information (Lowe and Pramono, 2006) instead of language structures. However, it is noted that this explanation warrants further empirical investigations.

6. Conclusion

This study examined the predictive effects of multi-dimensional factors of digital nativity on both favorable and adverse usage of Smartphones in Chinese college English learning. It was found that (1) digital nativity consisted of four factors; (2) a second-order factor of favorable Smartphone usage with first-order adverse effects in English learning was confirmed; (3) "Grow up with technology" significantly positively predicted favorable Smartphone use but negatively predicted adverse effects. "Thrive on instant gratification and rewards" significantly predicted both favorable and adverse effects in a positive way. However, "comfortable with multitasking" and "reliant on graphics for communication" could not predict Smartphones usage in English learning. Thus, the four digital attributes exerted different effects on Smartphones usage for Chinese college students' English learning. Findings reveal the significance of defining digital nativity as an intricate and multifaceted construct (Wang et al., 2019). The different predictive effects of the four factors on Smartphone usage for both positive and negative purposes help us better understand how individuals' psychological characteristics affect their behavior technologically advanced learning environment (Huang et al., 2021; Zhao and Zhao, 2021).

Our results provide some pedagogical implications for EFL learning and teaching in digital environments. First, teachers are suggested to be fully aware of the technological savviness of modern digital natives and proactively explore, select, and introduce high-quality digital resources (Kesharwani, 2020) for English learning to the students. Thus, realizing the role transfer from instructor and transmitter to the facilitator (Tapscott, 1999), information provider, communicator, knowledge-building supporter, and manager (Gonzalez, 2010) is essential and helpful. Teachers should give more trust to modern learners in exploring the beneficial functions of mobile devices and avoiding harsh effects. Thus, teachers are suggested to create a more encouraging environment and readily take advice from resourceful students to nurture friendly and generative surroundings. Second, the online group discussion forum is encouraged to be established so that answers to language learning questions are elicited from teachers and peer students, thus forming a collaborative learning environment (Oblinger and Oblinger, 2005; Tapscott, 2009). A student-centered (Jones and Shao, 2011) collaborating learning platform can relieve teachers' heavy burdens of answering too many questions and impel students' negotiation and concertation in dealing with language learning problems through peer learning. Finally, sufficient instructions in avoiding the adverse effects of technology (Kirschner and De Bruyckere, 2017) are required as an indispensable part of mobile-assisted language learning processes.

There are still some limitations in our study despite the informative results. First, this study is cross-sectional, which allows us to draw tentative conclusions on the causal effects of digital nativity on Smartphone usage. It is suggested to apply longitudinal designs to test structural relationships and their stability across a period. Second, this study used self-report questionnaires, which might limit the objectivity of the results since respondents might need to answer the questionnaires accurately. In response to this issue, other approaches to data elicitation (e.g., interview, reflective journal, and immediate stimulative recall after a task) are encouraged to collect multiple sources for triangulating the results. Finally, the English proficiency levels of participants and more individual variables need to be considered when exploring relationships between digital natives and their Smartphone usages, such as digital literacy, self-efficacy, learning motivation, self-regulation, and learning contexts.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Ethical Committee of the Northeastern University. The patients/participants provided their written informed consent to participate in this study.

Author contributions

LT and LH worked on research design conception, data analysis, and manuscript draft. FG worked on data collection and analysis. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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Views of secondary education teachers on the use of mixed reality

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The advance of the so-called emergent technologies in the field of education goes hand in hand with the previous experiences and beliefs of teachers, or lack thereof, with and about them. Among all the digital resources available, Mixed Reality (MR) is currently awakening the interest of educators, given that it combines virtual and augmented reality. Although both of these technologies are already present in many mixed methodologies utilized for teaching and learning processes, this is not the case of MR. Thus, it is necessary to discover the perspectives of educators on the use of MR, to be able to forecast its successful implementation in classrooms. Thus, the present article shows data obtained from a study with 219 Secondary Education pre-service teachers in Spain. The data collected through a 31-item *ad hoc* questionnaire pointed to differences in the perception of Mixed Reality in the teaching process as a function of gender, with women considering that it will make the classroom methodology more communicative, also believing that it will promote the reading comprehension of the texts that are utilized in each school subject. Thus, we can conclude that mixed reality is defined as a tool that promotes the learning process of secondary school students.

KEYWORDS

virtual reality, augmented reality, mixed reality, teachers, training, emergent technologies

Introduction

Presently, moving forward in the digital world must be understood by citizens as a right and a responsibility. With respect to a right, it implies the inclusion of all collectives in the construction of life in a society in general, and their immediate surroundings in particular (Restrepo and Gómez, 2020), where the main objective is to promote the inclusion of everyone into the idea of creating shared progress that benefits the entire population. If we focus on the responsibility aspect, it is associated to the beliefs, ethical codes, opinions, etc., of every individual, with all of this affecting a person and everything around him or her (García et al., 2022). Nevertheless, it is known that for the construction and re-construction of digital society to move forward, the participation of all the productive sectors is needed. In this sense, we must consider that digital resources

form part of all (or almost all) the actions that shape the everyday life of individuals. Thus, if we focus on the area of education, we will observe that due to the SARS-CoV-2 virus (COVID-19), its presence has considerably increased (Kauz, 2022). Along this line, technologies such as virtual and augmented reality, and more recently mixed reality, have been gaining a foothold in the classroom methodologies at all levels of education (Barroso and Gallego, 2017; Lee et al., 2018; Leal, 2020; Villalustre, 2020; Magallanes et al., 2021; Ayuso et al., 2022).

Focusing our attention on mixed reality (from here on MR), it implies a step forward when referring to technological development within the area of immersion into reality. Born under the sum of virtual reality (from here on VR), and augmented reality (from here on AR), little by little we have observed its overlap in the area of teaching at all levels of education, as we have pointed out. MR allows the students to immerse themselves in total learning (Marín-Díaz et al., 2022a), named immersive learning (meaning one's introduction into an artificial world), inherited from VR (Barroso and Gallego, 2017; Marín-Díaz et al., 2022b), which allows delving into contents that could be excessively abstract for the comprehension of students (Marín-Díaz et al., 2022a,b).

On the other hand, it must be pointed out that both (VR and AR) technologies have a series of limitations, as pointed out by Aslana et al. (2019), given that the individual is limited when using them, as in the case of VR, it isolates the user from the environment in which he or she moves, and for AR, the perception of reality and immersion is not complete, given that we do not "incorporate" into the new scenario, but are merely observers.

MR arrived to schools thanks to reports such as Horizon (Johnson et al., 2016), which point to the degree of penetration that this and other technologies will have in the coming years, as well as the restless spirit of researchers and education practitioners. As already pointed out, MR is a step forward in the immersion of a subject in a completely virtual scenario, where his or her interaction with what it is observed can be total (Bockholt, 2017). From VR, MR has taken the virtual scenarios created with the 360° video technology utilized, and from AR, the possibility of visually projecting, with movement, that which we wish to try, see, "touch", etc., to ultimately experience it in first person.

Ultimately, MR combines three elements; immersion, simulation, and interaction. *A priori*, we understand that the first element brings with it the introduction of a completely unreal virtual scenario (here we talk about the part that incorporates VR), where what we see is not real, but a superimposed hologram, for example (here we talk about AR). Thus, we can talk about a simulation, given that what is provided is a well-simulated sequence in which we will be able to directly interact with objects, people, situations, etc., which can be observed within it (Marín-Díaz et al., 2022a,b).

On the other hand, we must consider that MR has great advantages, for example the visual richness that it provides to the contents, which will promote learning, thus turning into one of the key elements for its incorporation into teaching-learning methodologies (Zhang, 2021). Aside from this, it also allows the student to interact with objects, thus making the act of learning more invigorating (Dalingera et al., 2020; Zhang, 2021; Marín-Díaz et al., 2022a). Lastly, another added value is that the risk factor disappears. For example, when we interact with a laboratory with dangerous materials, the student is not at risk at all (Rossler et al., 2020).

An example of the education + MR association is found in the DICOM3D-VR application created by Sadeghi et al. (2021) which allows, through the application of models in three dimensions combined with MR, the evaluation of doctors in clinical pictures of a patient to be done in less than 1 min without losing image data, as we find with other three-dimensional models, so that the education of health professionals is improved. Still within the field of health and along the same line as Sadeghi et al. (2021), we find the study by Tennant et al. (2021) with children and adolescents under oncological treatment. Her study, whose aim was for patients to have a better understanding of the treatment process, and to provide them with education for health, showed that through the use of MR, their understanding of the medical process improved, at the same time that their states of anxiety were reduced.

Outside from the field of health, we find the work by Zhang (2021), who discussed advances on the use of MR with Early Childhood pre-service teachers. In this study, the author pointed out that its use will allow us to further explore the individual differences of the subjects (children), including how their environment affects the characteristics that define their personality, all of this through the use of avatars that simulate students, so that it imitates the complete ecology of an early childhood classroom.

As pointed out by Miller (2017), overlapping MR with education processes means introducing ourselves into an immersive experience through tangible and verbal interaction, which will promote the mobilization of skills needed by the subject to learn, both consciously and unconsciously, given that the information is presented in a realistic and authentic manner, and as a result, the retention in our memory is increased, with the memory firmly recorded (Marín-Díaz et al., 2022).

Given the above, the present study will try to determine, to the greatest extent possible, the views of teachers in the Social Sciences and Experimental Sciences fields, who work in Spanish Compulsory Secondary Education centers, on MR in their professional field, under the auspices of the R&D + I project *Design, implementation and evaluation of Mixed Reality materials for learning environments* (PID2019-108933GB-I00), financed by the Ministry of Science and Universities of Spain.

Materials and methods

For the present study, an *ex post* facto method was utilized, with a descriptive and correlational design, based on the classification by Jorrin et al. (2021). Beginning with this, the starting objectives were defined, which were based on the general objectives of the R&D + I Project within which the present study is framed, the Design, implementation and evaluation of Mixed Reality materials for learning environments (PID2019-108933GB-I00), financed by the Ministry of Science and Universities of Spain. The objective of the general project was the implementation and evaluation of MR materials in secondary education. Thus, the main starting objective of the present study was to determine the views on the use of MR, of teachers-in-training enrolled in the specialties of Social Sciences and Experimental Sciences Master's in Secondary Education Teaching at the University of Córdoba (Spain). The following working hypotheses were posited:

a) H1. There are differences according to gender on the use of MR in classrooms. More specifically, women value the attention to diversity in the use of MR in the Obligatory Secondary Education.
b) H2. The age of the teachers-in-training does not show differences on the use of MR in classrooms.
c) H3. There are significant differences according to the macro-area from which Obligatory Secondary Education pre-service teachers come from, with those from the Social Sciences valuing the attention to diversity in the use of MR.

Instrument

The collection of data was conducted through the implementation of a questionnaire through the Google Forms service.

The instrument was composed by 31 items, which were organized into two blocks: the first contained the socio-demographic data of the participants, in this case their gender, age, and macro-area. The second contained the other 28 items, which dealt with MR itself. The response scale was Likert-type, following the guidelines from Matas (2018) where one corresponded to complete disagreement, and five complete agreement.

For scientific rigor, a series of statistic tests were performed to determine its reliability and validity. To verify the reliability of the instrument, a Cronbach's alpha test was performed, which provided a value of 0.865, as well as McDonald' Omega, which provided a value of 0.827, both of which were considered by López-Roldán and Fachelli (2016) as being very high. Also, for further scientific rigor, the same tests were also performed after removing one item at a time, with the values found oscillating between 0.850 and 0.832, both of which were deemed acceptable (Ventura-León and Caycho-Rodríguez, 2017).

For validity, an exploratory factorial analysis (EFA) was performed, which was delimited to accept only the items with loads higher than 0.30 (Mavrou, 2015), this screening resulted in eight items of the 36 not being considered in the distribution of three factors that explained 43.0% of the variance (see **Table 1**). The extraction method utilized was unweighted least squares (ULS) and Kaiser normalization with oblimin rotation, with Kaiser-Meyer-Olkin (KMO) values obtained being 0.820 (acceptable), and a significant Bartlett's sphericity test [X^2 (378) = 2380.909 and $p < 0.001$]. Considering these parameters, the factorial structure was accepted (Ferrando and Anguiano-Carrasco, 2010).

All of these validity results, a not very large sample size, together with the extraction of various items, led us to replicate the test with the software Factor Analysis (v.11), to verify the structure through statistic tests that corroborate this structure (Freiberg et al., 2013). The three factor structure was re-affirmed through the use of the factor extraction method Robust Unweighted Least Squares (RULS) and a varimax promin rotation with Kaiser normalization procedure (Lorenzo-Seva and Ferrando, 2019), when using Pearson's correlations (KMO = 0.867; Bartlett's sphericity test: X^2 = 2373.6; gl; 630; sig < 0.01), and a recommended configuration of three factors, with the statistical values obtained (95% CI) being: CFI = 0.978; BIC = 1531.880; GFI = 0.957; AGFI = 0.941; RMSR = 0.0691; and an RMSEA = 0.045, below 0.05, considered acceptable (Escobedo et al., 2016).

Once the factors were defined, they were subjected to the reliability test, with high or very high values obtained (Rodríguez-Rodríguez and Reguant-Álvarez, 2020) (see **Table 2**).

Participants

The study population was composed by all the students enrolled in the Secondary Education Teacher's training Master's program taught at the University of XX during academic year 2021–2022, obtained through non-probabilistic, convenience sampling (Otzen and Manterola, 2017; Hernández and Carpio, 2019). From this population (N = 219), the sample extracted for the present study was composed by pre-service teachers in the macro-areas of Social Sciences and Experimental Sciences, of which 58.4% were women, and 41.6% men. Considering the macro-areas, 60.3% were found in Social Sciences, and 39.7% in Experimental Sciences.

With respect to the age of the participants, their mean age was 26.71 years old (SD = 5.378), (see **Figure 1**).

Analysis strategy

The analysis of the quantitative data will be first descriptive, through the use of central tendency and dispersion (mean and

TABLE 1 Exploratory factor analysis.

		Factors		
		1	2	3
1.	The use of MR will promotes the critical spirit of the students	0.732		
2.	The use of MR promotes the ability to dialogue and express oneself in public associated to the school subject in which it is utilized	0.708		
3.	The use of MR promotes values education	0.667		
4.	The use of MR will make it so that the didactic methodology utilized in the classroom will achieve more of the objectives of the subject in which it is used	0.650		
5.	The use of MR will make the didactic methodology utilized in the classroom promote the development of key competences	0.646		
6.	The use of MR will favor the personal initiative of the students	0.615		
7.	The use of MR promotes the oral expression associated to the school subject in which it is utilized	0.608		
8.	The use of MR will favor the student's ability to communicate what was learned	0.588		
9.	The use of MR promotes the reading comprehension of the texts associated to the school subject in which it is utilized	0.585		
10.	The use of MR will make the didactic methodology utilized in class more communicative	0.562		
11.	The use of MR will favor the creativity of the students	0.547		
12.	The use of MR will make the didactic methodology utilized in the classroom more active	0.535		
13.	The use of MR will make the didactic methodology utilized in class more participative	0.490		
14.	The use of MR can promote multicultural education	0.471		
15.	Learning how to use MR, on the part of the teachers, takes too much time		0.711	
16.	Learning how to use MR, on the part of the students, takes too much time		0.576	
17.	For using MR in the classroom, great technological support is needed (tablets, markers, screens. . .)		0.567	
18.	For using MR in the classroom, the teachers must have knowledge about informatics and/or programming		0.558	
19.	For using MR in the classroom, students must have knowledge about informatics and/or programming		0.479	
20.	RM can be used by subjects with hearing difficulties			0.872
21.	RM can be used by used by subjects with psychological disorders			0.824
22.	RM can be used by individuals with motor difficulties			0.747
23.	RM can be used by students with specific education needs			0.746
24.	RM can be used by gifted individuals			0.645
25.	The use of RM can promote cross-sectional learning of the contents			0.465
26.	The use of RM allows cooperative work between students			0.448
27.	The use of RM allows collaborative work between students			0.425
28.	The use of RM allows group work between students			0.413

standard deviations), and distribution (kurtosis). Secondly, an inferential analysis will be performed with the variables gender, macro-areas, and age, and thirdly, a relational analysis of these factors as well.

Results

Descriptive study

In first place, the descriptive study of the factors (see Table 3) shows that the factors followed a normal distribution, given that the kurtosis values were found between the +1 and −1 interval. On the other hand, the participants were more in agreement that the use of MR in the classroom methodology will favor personal initiative (M. = 4.06; SD = 0.736), and students will be more active (M. = 4.42; SD = 0.753) and more participative (M. = 4.27; SD = 0.770). Likewise, they were completely in agreement that for attention to diversity, the use of MR could be utilized by students who had specific learning needs (M. = 4.34; SD = 0.726), gifted (M. = 4.54; SD = 0.637), with hearing (M. = 4.23; SD = 0.720), and motor (M. = 4.01; SD = 0.815) difficulties, aside from allowing cooperative (M. = 4.29; SD = 0.721) and collaborative (M. = 4.26; SD = 0.706) work. Finally, they were in agreement that for the

TABLE 2 Reliability of the factors.

	Cronbach's alpha	McDonald's omega
Factor 1. Teaching methodology in the use of MR	0.852	0.844
Factor 2. Technology training on the use of MR	0.738	0.723
Factor 3. Attention to diversity on the use of MR	0.834	0.814

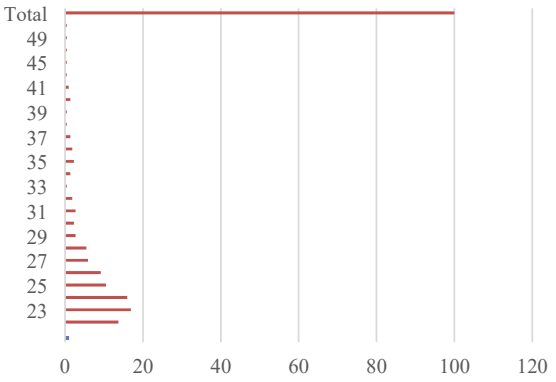

FIGURE 1
Distribution of the sample as a function of age.

use of MR in the classroom to be a reality, the teachers needed technology training or education (M. = 3.76; SD = 1.134), as well as technological support (M. = 3.81; SD = 1.053).

Inferential study

The inferential study performed refers to the differences in means. In this case, for the variables gender and macro-area, Student's *t*-test (n.s. = 0.05) was used for independent variables.

The results revealed that women are more in agreement with the assertions that give rise to factor 1 (teaching methodologies in the use of MR), than the men (assuming equal variances $t = -2.622$ and $p = 0.009$, Cohen's d = 0.485). And that pre-service teachers in the macro-areas of Social Sciences are more in agreement with the statements that referred to the teaching methodology in the use of MR (factor 1), than those from Experimental Sciences (assuming equal variances $t = 2.986$ and $p = 0.002$, Cohen's d = 0.484).

The comparison of the variable age was performed with an ANOVA analysis (n.s. = 0.05), resulting in an effect between the variable age and Factor 3 (Attention to diversity in the use of MR), F (2, 216) = 4.193 and $p = 0.016$, $Eta^2 = 0.037$ and $Epsilon^2 = 0.028$, where subjects aged between 21 and 30 years old were more in agreement than those aged 31 to 40 years old ($t = 2.328$ and $p = 0.021$, Cohen's d = 0.471). The rest of the differences were not significant.

Correlational study

Lastly, we present the relational study, by first executing a bivariate correlation to verify the existence of a relationship between the research factors, pointing out the existence of a low and notable relationship, and a high significance of 0.01 (**) and 0.05 (*), depending on the variables considered (see Table 4).

Factor 1 (Teaching methodology in the use of MR), is moderately or notably associated with factor 3 (Attention to diversity in the use of MR), R = 0.465 and $p < 0.001$. Meanwhile, factor 1 (Teaching methodology in the use of MR) is not well associated with factor 2 (Technology training on the use of MR) R = 0.150 and $p = 0.026$. There was no relation between factors 2 and 3.

With respect to these relationships, we tried to decipher the model that explains factor 1 as a function of the other variables, given that it has a relationship with the rest. For this, a stepwise multiple linear regression analysis was performed (see Table 5), where the dependent variable was the Teaching methodology in the use of MR (factor 1), and the independent or predictive variables were factor 2 (Technology training on the use of MR), and factor 3 (Attention to diversity in the use of MR), as well as the socio-demographic variables gender and macro-area (only had two categories), and the variables age, without categorization.

The result showed that only 23% was explained with the following equation: Factor 1 = 21.476 + 0.74 Factor 3 + 0.24 Factor 2, given the level of adjusted $R^2 = 0.227$ and a Durbin-Watson value of 1.9, with F (2, 216) = 33.058 and $p < 0.001$ (n.s. = 0.05), thus showing the interdependence of the residues, and that the explanatory variables have a joint and linear influence on factor 1.

Factor 1 is not explained by neither age, gender, nor macro-area, while factor 3 ($t = 7.729$ and $p < 0.001$), and factor 2 ($t = 2.277$ and $p = 0.024$) were kept, with both of them significant for the Teaching methodology in the use of MR (factor 1).

Therefore, we decided to study the predictive variables eliminated from the model as selection variables, through a stepwise multiple regression analysis. For gender, as shown in Table 6, the model still explains factor 1 with the same variables, but with different parameters for the men, while for the women, it does not take into account factor 2.

TABLE 3 Descriptive study.

						Asymmetry		Kurtosis	
	N	Min.	Max.	Media	D.T.	Statistic value	S.E.	Statistic value	S.E.
Factor 1	219	33	70	53.8	6.88	0.044	0.164	0.222	0.327
Factor 2	219	7	25	16.6	3.84	−0.095	0.164	−0.480	0.327
Factor 3	219	17	45	38.3	4.29	−0.733	0.164	1.003	0.327

TABLE 4 Correlational study.

		Factor 1	Factor 2	Factor 3
Factor 1	Pearson's correlation	1		
	Sig. (two-tailed)			
	N	219		
Factor 2	Pearson's correlation	0.150*	1	
	Sig. (two-tailed)	0.026		
	N	219	219	
Factor 3	Pearson's correlation	0.465**	0.032	1
	Sig. (two-tailed)	0.000	0.637	
	N	219	219	219

*High significance of 0.05.
**High significance of 0.01.

TABLE 5 Multiple linear regression for the Teaching methodology in the use of mixed reality (MR).

	Constant	Factor 3	Factor 2
B	21.476	0.739	0.243
S.E.	4.035	0.096	0.107
Beta		0.460	0.136
t	5.322	7.729	2.277
Sig.	0.000	0.000	0.024
Zero order		0.465	0.150
Partial R		0.465	0.153
Semi-partial R		0.460	0.136
Tolerance		0.999	0.999
VIF		1.001	1.001

TABLE 6 Multiple linear regression for the Teaching methodology in the use of mixed reality (MR) according to gender.

	Men			Women	
	Constant	Factor 3	Factor 2	Constant	Factor 3
B	25.809	0.514	0.444	21.721	0.855
S.E.	5.697	0.144	0.172	4.981	0.128
Beta		0.343	0.249		0.511
t	4.530	3.557	2.581	4.361	6.677
Sig.	0.000	0.001	0.012	0.000	0.000
Zero Order		0.386	0.309		0.511
Partial R		0.355	0.265		0.511
Semi-partial R		0.337	0.245		0.511
Tolerance		0.969	0.969		1.000
VIF		1.032	1.032		1.000

With respect to the result for the men, we find that only 19%, is explained with equation: Factor 1 = 25.8 + 0.51 Factor 3 + 0.44 Factor 2, given an adjusted R^2 = 0.191 and Durbin-Watson value of 2.1, with F (2, 88) = 11.628 and $p < 0.001$ (n.s. = 0.05), showing the interdependence of the residues and that the explanatory variables have a joint and linear influence on factor 1. Both factor s3 (t = 3.557 and p = 0.001) and factor 2 (t = 2.581 and p = 0.012), were significant for the Teaching methodology on the use of MR (factor 1).

While for the women, 26% is explained with equation: Factor 1 = 21.7 + 0.85 Factor 3, given an adjusted R^2 = 0.256 and Durbin-Watson value of 1.9, with F (1, 126) = 44.586 and $p < 0.001$ (n.s. = 0.05), showing the interdependence of the residues and that the explanatory variables have a joint and linear influence on factor 1. Factor 3 (t = 6.677 and $p < 0.001$) is significant for the Teaching methodology on the use of MR (factor 1).

Likewise, the predictive variables macro-areas, as selection variables, were analyzed through a stepwise multiple linear regression analysis. Table 7 shows that the model still explains factor 1 with the same variables but with different parameters for the pre-service teachers in social sciences, while for experimental sciences, only factor 3 is considered.

The result of Social Sciences is that only 25% is explained with the following equation: Factor 1 = 17.8 + 0.80 Factor 3 + 0.37 Factor 2, given an adjusted R^2 = 0.245 and Durbin-Watson value of 2.0, with F (2, 129) = 22.211 and $p < 0.001$ (n.s. = 0.05), showing the interdependence of the residues and that the explanatory variables have a joint and linear influence on factor 1. Both factor 3 (t = 6.257 and $p < 0.001$) and factor 2 (t = 2.422 and p = 0.017), were significant for the Teaching methodology on the use of MR (factor 1).

While for Experimental Sciences, 23% was explained with the following equation: Factor 1 = 27.1 + 0.66 Factor 3, given an adjusted R^2 = 0.225 and Durbin-Watson value of 1.8, with F (1, 85) = 25.970 and $p < 0.001$ (n.s. = 0.05), showing the interdependence of the residues and that the explanatory variables have a joint and linear influence on factor 1. Factor 3 (t = 5.096 and $p < 0.001$) is significant for the Teaching methodology on the use of MR (factor 1).

TABLE 7 Multiple linear regression for the Teaching methodology in the use of mixed reality (MR) for the macro-area.

	Social sciences			Experimental sciences	
	Constant	Factor 3	Factor 2	Constant	Factor 3
B	17.832	0.804	0.371	27.059	0.657
S.E.	5.625	0.129	0.153	4.961	0.129
Beta		0.475	0.184		0.484
t	3.170	6.257	2.422	5.454	5.096
Sig.	0.002	0.000	0.017	0.000	0.000
Zero order		0.472	0.174		0.484
Partial R		0.483	0.209		0.484
Semi-partial R		0.475	0.184		0.484
Tolerance		1.000	1.000		1.000
VIF		1.000	1.000		1.000

The variable age as a selection variable in the stepwise multiple regression analysis, did not show an explanatory model for the Teaching methodology on the use of MR (factor 1).

The non-multi-collinearity of all the models, observed through VIF and tolerance values, was adequate, according to Vilà et al. (2019), given that the values of the first parameter were equal or higher than 1, and the second were higher than 0.10.

Discussion and conclusion

We agree with Huang et al. (2016) in that the addition of digital resources to classrooms has provided teaching innovation with a new perspective, which implies the endowment of resources, as well as the training of teachers and students. However, so that a digital tool can be truly introduced into the methodology, or the manner in which teaching is performed, it is necessary for the teachers to express their beliefs, opinions, and experiences with them (Arancibia et al., 2020; Marín et al., 2022). As a result, studies on these views are necessary so we can move forward in the process of learning, to also promote the development of the digital competence of students, which is presently a key pillar in their incorporation to the society and the professional world.

In the specific case of our object of study, MR, we initially verified that pre-service secondary education teachers associate it with 3 factors, i.e., the teaching or classroom methodology, training, and attention to diversity, just as studies by Marín-Díaz et al. (2022c).

As for aspects associated to the teaching methodology, the participants pointed out that MR will promote the autonomy and initiative of secondary education students, and also indicated that the classroom and the learning process would be more active (Tang et al., 2018; Alfadil, 2021; Sousa et al., 2022), and therefore, more participative.

Just as the results obtained in a study by Meyer et al. (2019) it is underlined that knowledge, i.e., being trained on the use of MR, plays an important role in the development of learning processes, and it is the reason why there is a need to promote the training of teachers on its proper use, in agreement with that expressed by the participants in our study and those from Fuentes et al. (2019) and Aso et al. (2021).

Training on the use of this technology is another of the worries expressed by the study participants, who pointed that they as teachers, as well as students in this education stage, need training that will allow them to implement it in the classroom, and to promote meaningful learning in the education community (Palomo, 2020). More specifically, the pre-service secondary education teachers, just as in the studies by Bower et al. (2020), Vasilevski and Birt (2020), Zhang (2021) pointed out the need to have technological support for its successful implementation in classrooms.

As for aspects associated to attention to diversity, the participants pointed out that students who were gifted, as well as those who had hearing difficulties, could benefit from its use, so that we can conclude that their learning would be enriched (Huang et al., 2019; Magallanes et al., 2021).

When considering the hypotheses posited, we verified that for hypothesis 1 (*There are differences according to gender on the use of MR in the classrooms. More specifically, women value the attention to diversity in the use of MR in the Obligatory Secondary Education*), we can consider that gender is an element that determines the presence of MR in the classroom, in the sense that women leaned toward its use as a resource in their teaching. Thus, H1 can be accepted in factor 1 (Teaching methodology in the use of MR), and rejected in factors 2 and 3 (Technology training on the use of MR, and Attention to diversity on the use of MR), as opposed from the results obtained by Bursztyn et al. (2017) and Marín-Díaz et al. (2022c).

If we consider age to obtain an answer to H2 (*The age of pre-service teachers does not show differences on the use of MR in classrooms*), we observed that no differences were found, so that the hypothesis can be accepted in the three factors, as opposed to the results obtained by Marín-Díaz et al. (2022c) with a study population that was similar to that in the present study.

Lastly, for the third hypothesis (*There are significant differences according to the macro-area from which Obligatory Secondary Education pre-service teachers come from, with those from the Social Sciences valuing the attention to diversity in the use of MR*), the results indicate that it must be accepted with respect to factor 3, as well as in factor 2, which refers to technology training (Bower et al., 2020; Vasilevski and Birt, 2020; Zhang, 2021). It is significant that for the participants from the macro-area of Experimental Sciences, the third factor affected the first, and not the other way around.

Ultimately, and to conclude, we can indicate that pre-service secondary education teachers had a very positive view about the use of MR in the classroom, and its introduction as a resource in their teaching methodologies, although they need training for this, as well as and endowment of resources. Likewise, they believe that learning would be more active and collaborative between the students.

Limitations

Studies conducted in the field of education have an initial handicap, which is the size of the sample utilized, and on which the study will be conducted. In this case, we are aware that an $N = 219$ does not allow us to generalize the results to the entire population of pre-service secondary education teachers. However, starting with the results obtained, the instrument can be perfected to be able to obtain one that has 100% of the guarantees of reliability and validity, to be able to generalize

it to the entire education community independently of the country it is applied.

Another limitation we found is that not all the education centers even possessed basic digital resources, so that MR, a very recent technology, will not be present in all the classrooms. Thus, the training of the teachers will also be a variable that will limit the study, given that if many of them do not have the training, they will not overlap its use with their classroom methodology.

Data availability statement

The data analyzed in this study cannot be made public due to a lack of authorization by the participants. Requests to access these datasets should be directed to VM-D, vmarin@uco.es.

Author contributions

VM-D: conceptualization, writing of the manuscript, review, editing, and supervision. VM-D and BS-R: methodology and analysis and review final document. Both authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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Development of the teacher's technological pedagogical content knowledge (TPACK) from the Lesson Study: A systematic review

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A systematic review is presented with the purpose of exploring the trends associated with the development of technological pedagogical content knowledge (TPACK) from Lesson Study. In the 21st century, technology established a complex and necessary relationship with different sectors of society, enabling different conceptual and practical models for the incorporation of technologies in teaching. TPACK was one of the most outstanding. In this perspective, a systematic literature review is presented taking into account 16 studies published between 2015 and 2021 with the purpose of analyzing the development of TPACK in teachers, in research that uses the Lesson Study (LS) as an intervention strategy. The review was carried out in April 2022 using the following databases: Scopus, Web of Science, Spinger Link, Proquest Central, Science Direct, Redalyc, Dialnet and Scielo. The phases of identification, screening, selection and inclusion of the flowchart of the PRISMA guide were applied. The results reveal that the LS constitutes a theoretical and practical framework that provides contextualized opportunities to work on the training needs and interests of teachers, promoting self-assessment and the construction of new conceptions about teaching with technologies. Therefore, the theoretical discussion reveals that the integrative vision of TPACK is the perspective that predominates the development of this type of research.

KEYWORDS

digital competence, TPACK, teacher training, Lesson Study, ICT, systematic review

1. Introduction

Various technologies digital and non-digital have been a key component in responding to the educational needs arising from the pandemic. This scenario marked by didactic and school management uncertainties made visible limitations and opportunities in educational models around the world, and in many cases, a moment of deep reflection to reconfigure pedagogical and investigative practices in educational establishments. This global situation allowed technologies to be positioned more vigorously, even turning them into indispensable learning resources with which families, teachers, and students managed to advance (Rivas, 2020). Thus, technology emerged as an important resource to enhance the skills of teachers and the

generation of better conditions for student learning in an unexpected context (Cabero and Valencia, 2021). However, in the field of teacher training and professional development, it remains a challenge to overcome the technocentric view of the technological component in order to mobilize it toward an understanding and implementation of situated teaching and learning experiences, where the integration of the components continues to be strengthened. Technological, pedagogical and disciplinary during classroom practices (Ortega, 2020). Similarly, the scarce digital competence of teachers for the integration of technologies in the curriculum and teaching (Cabero-Almenara, 2020) continues to constitute a complex and problematizing scenario that invites us to think and transcend the recognition of ICT as a technical tool., toward a deeper understanding of its implications in the teaching and learning of school content (Cadena, 2020). In this context, an alternative way to achieve the development of TPACK in teachers is the use of Lesson Study (LS), which is a model of teacher professional development aimed at improving the pedagogical practice of teachers based on the collaborative study of their own teaching actions (Pérez and Soto, 2015).

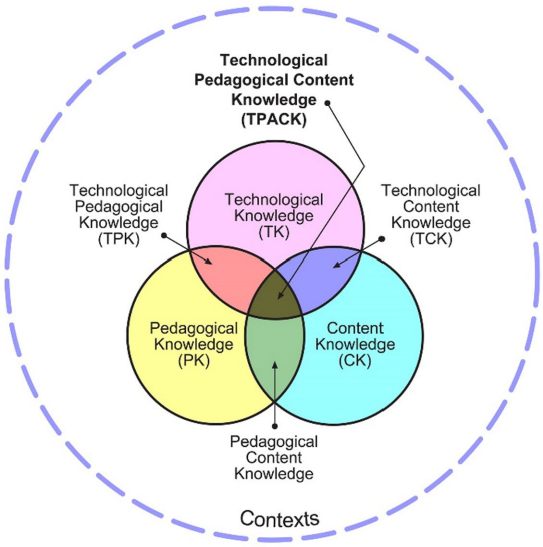

FIGURE 1
Representation of the TPACK. Source: Mishra and Koehler (2006).

1.1. TPACK

From an alternative perspective, Mishra and Koehler (2006) proposed the TPACK model as a powerful theoretical framework that seeks the curricular integration of the technological component, with special emphasis on the efficient implementation of ICT to improve the teaching and learning of school content. The studies that gave rise to this model investigated the knowledge that teachers required to adequately incorporate technology in their teaching, as well as the ways to develop it. In this model, three domains of knowledge converge in an integrated manner, namely: technological knowledge, pedagogical knowledge and content knowledge. This understanding assumes a different role for teachers, as well as the transformation of their educational experiences and training processes, emphasizing the importance of the acquisition and development of different technological skills that enable varied and effective ways for good teaching with technologies. The TPACK model has been studied in the last 20 years from various epistemological and methodological positions by different authors: Margerum-Leys and Marx (2002), Angeli (2005), Niess (2005), Cabero (2014), Pierson (2014), and Harris et al. (2017).

Mishra and Koehler (2006) conceptualize the TPACK framework in terms of seven domains of knowledge (Figure 1), namely: (a) content knowledge (CK), which corresponds to knowledge of the topic that is intended to be learned or taught; (b) pedagogical knowledge (PK), which is knowledge about teaching and learning strategies; (c) technological knowledge (TK) which constitutes knowledge about operational digital technologies; (d) pedagogical content knowledge (PCK) that responds to the understanding and representation that the teacher makes of the specific teaching content for its teachability and learnability; (e) technological content knowledge (TCK) that corresponds to the understanding and representation that the teacher makes about how a technology can enhance or limit a specific teaching content; (f) technological pedagogical knowledge (TPK) that accounts for the understanding and representation that a teacher makes about how a technology influences the strategies used in his pedagogical action, and (g) technological pedagogical knowledge of the content (TPCK) that arises from the integration of PCK, TCK and TPK, this knowledge corresponds to the understanding and representation that a teacher makes for a good teaching of content with technology. Studying TPACK in this sense primarily involves understanding how good teaching with technology is developed *in situ* in teacher training and professional development.

1.2. Lesson Study

The Lesson Study, hereinafter LS, emerges as a model for teacher training characterized by its high contribution to teaching research through the collaborative participation of teachers in making curricular decisions, in interactive teaching and critical reflection of pedagogical practice (Pérez and Soto, 2015). It had its origins in Japan (Isoda, 2007) as a model that allowed the rupture of individual and traditional education that prevailed at the end of the 19th century.

The LS, according to Pérez and Soto (2015), is structured in 4 phases; The first corresponds to the analysis of the study plan to identify the topic of interest and formulate the learning objective of the students. The second accounts for class planning under the principle of anticipating student thinking, justifying the selection of the teaching model and establishing a plan for data capture. The third, related to the realization of the class, where a teacher carries out the designed plan while others observe and collect the data. And the fourth moment that allows us to reflect on the observation of the class using the data to analyze and establish the questions that arise in teaching and learning. This cyclical exercise allows consolidating and adjusting the teaching with new questions to perfect the teaching process that results in good learning. The LS is a teacher training strategy that has expanded its research and training scope to the United States with Fernández (2002) and Lewis (2002), to Europe with Pérez and Soto (2015) and Dudley

(2012). Likewise, in Colombia, the Ministry of National Education (MEN) developed the experience between 2003 and 2008 (Theran, 2018).

It is important to highlight that the TPACK requires a training scenario that allows the teacher to understand the various situations that emerge from their own teaching activity, as well as the development of the knowledge required in their professional activity. In this sense, a situated, collaborative approach is pointed out, where the teacher learns from his activity and from the reflection derived from his practice (Valanides and Angeli, 2008), elements that are associated with SL and that can also become in a coherent alternative for the strengthening of its technological competences. In this sense, it is assumed that implementing the LS to develop the TPACK is to generate a collective plan to understand the variables that arise when using ICT. That is, to design new ways of teaching where it is key to observe the curricular designs and didactics and create a harmonious climate for discussion and collective understanding of everything that is being done; In short, it is an honest exchange, a space to open thoughts, ideas, beliefs and the classroom to critically study teaching with technologies.

This systematic review sets out to explore emerging trends associated with the development of TPACK through LS, unveiling possible directions and providing answers that are currently unclear in the theoretical and practical relationship of these two models. Therefore, this work intends to build a state of the art that reveals the theoretical and methodological perspectives, the findings, the benefits and limitations arising from the studies that aimed to develop the TPACK through the LS.

2. Materials and methods

This research appeals to the use of the descriptive content analysis method, which allows examining and structuring qualitative and quantitative studies to identify trends related to each other (Ültay et al., 2021). Likewise, the contributions of Moher et al. (2009) were taken into account in accordance with the PRISMA guide following the questions:

In what continents and countries are the investigations that develop the TPACK based on the LS located?

At what educational levels and specific disciplines have the research that develops the TPACK from the LS been implemented?

Who are the participants that are part of the research that develops the TPACK from the LS?

How are the investigations on the development of the TPACK that have used the LS as a teacher training strategy designed?

How are the TPACK and LS models understood in the framework of these investigations?

What difficulties have researchers found in these investigations that develop the TPACK from the LS?

What are the conclusions derived from these works that develop the TPACK from the LS?

1. Inclusion criteria: (a) papers of research or review results that combine the TPACK and LS models in their title, abstract or keywords; (b) papers published between 2015 and 2021 and (c) papers written in Spanish and English.
2. Exclusion criteria: (a) studies that are not within the typology of papers and (b) papers that do not allow free and complete access.
3. Search strategy: equations were defined in English and Spanish, using Boolean operators ALL, AND, OR and NOT. Several tests and iterations of the equation and of each of the selected descriptors were made until the definitive equation was found that allowed the finding of the related data in this systematic review: TPACK AND "LESSON STUDY." Next, the advanced search options of the *Scopus, Web Of Science, Spinger Link, Proquest Central, Science Direct, Redalyc, Dialnet* and *Scielo databases* were used to specifically focus the studies.

In turn, a flowchart represented in Figure 2 was configured, where the selection of studies was presented, indicating the size of the sample (number of papers) by databases, the screening and inclusion process, indicating the number of papers for each case (Moher et al., 2009).

According to the established criteria, in the identification phase, 6 duplicate papers were targeted through the Mendely application and Endnote Web. From the reading in the screening, 49 were discarded, mainly because they did not combine the TPACK and LS models in teacher training processes. According to the reading of the title, abstract and keywords, 16 papers were considered adequate, as shown in Table 1.

3. Results

Most of the studies (10/16) that combine the TPACK and LS categories are located on the Asian continent, the largest number in Indonesia (4), two in the Philippines, two in Turkey, one in China and one in Thailand. The above phenomenon can be associated with the fact that LS emerged in Asia, where its impact and visibility have been more relevant. Pérez and Soto (2007) point out that the theoretical debate that has taken place at the international level shows an approach to the multiple, plural and complementary ways of putting SL into practice, especially in the context of Southeast Asia. Likewise, there is research in Puerto Rico (2), South Africa, Ireland, Canada and the United States, the latter influenced by research that explored the viability of LS in the US (Fernández, 2002) (Table 2).

Table 3 shows the educational levels and the disciplinary domains with which the investigations were developed. Most of the studies are located at the secondary education and higher education levels, seven (7) of the sixteen (16) studies focus on the disciplines of mathematics (5) and science (3), followed by the disciplines of chemistry (2), physical sciences (2), English (1), and physical education (1). One study did not indicate the specific discipline, since it focused on the development of TPACK through the LS through courses for teachers to acquire knowledge and skills to learn to teach with technology in an interdisciplinary manner.

Table 4 shows the participants who were part of the research, of which the studies reveal that 113 were teachers in initial training and 242 teachers in service. In relation to teachers in initial training, it was observed that the experience developed with a smaller number of participants (3) was that of Paristiowati et al. (2020), while the research by Darsih et al. (2021) developed with in-service teachers was the one with the fewest participants (3). In turn, the investigations that had a

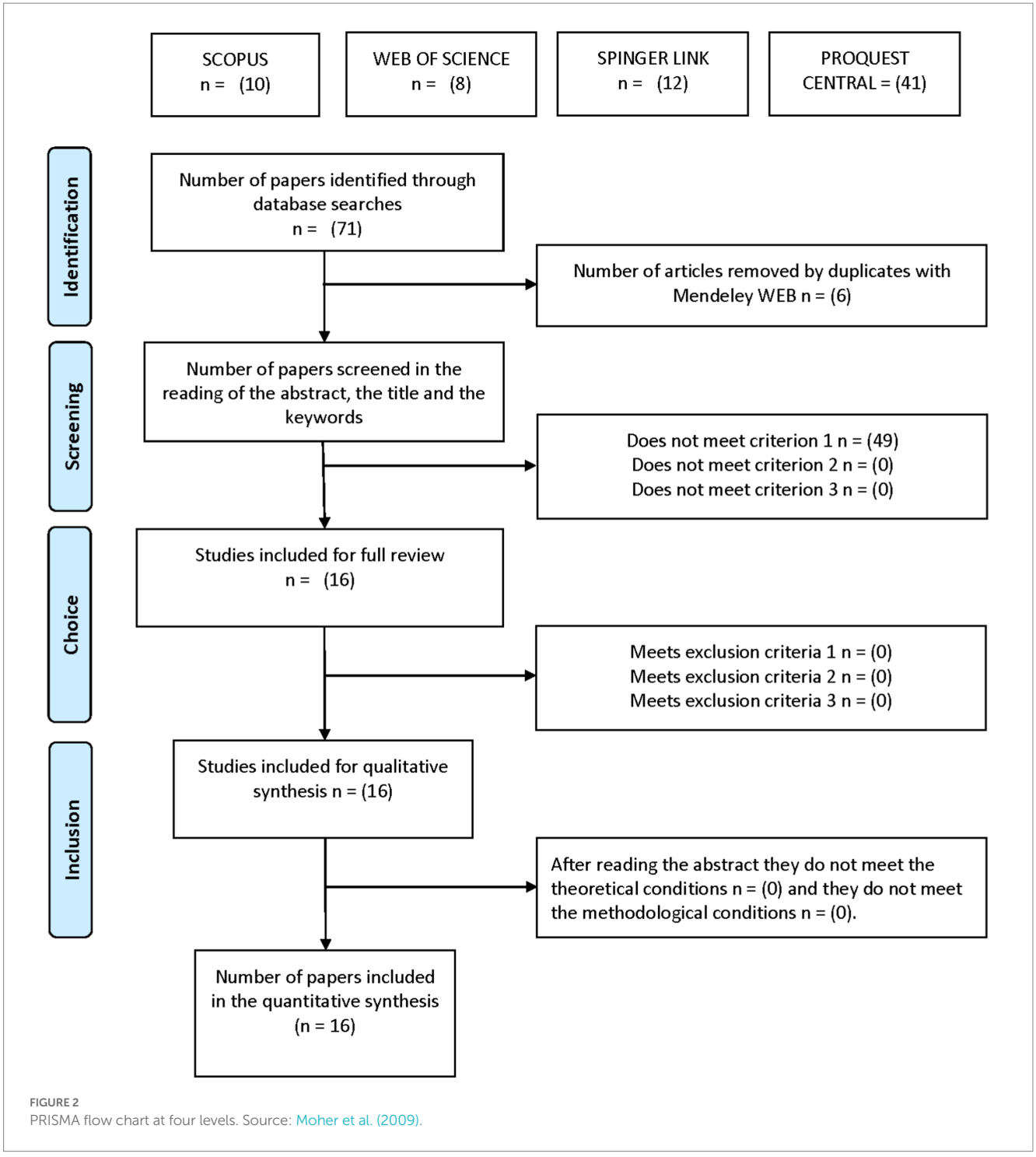

FIGURE 2
PRISMA flow chart at four levels. Source: Moher et al. (2009).

high number of participants were that of Zhou et al. (2017) with 65 teachers in initial training and that of Carpenter and Munshower (2020) with 120 teachers in service.

Now, the LS shows that the teaching and learning cycle of this strategy is implemented with a small group of teachers; between 3 to 6 (Stigler and Hiebert, 1999). In this sense, seven (7) of the investigations were carried out among this range of participants (Kurt and Çakıroğlu, 2018; Paristiowati et al., 2020; Anci et al., 2021; Darsih et al., 2021; Hernández-Rodríguez et al., 2021; Huang et al., 2021; Marron and Coulter, 2021), which indicates that the SL is undergoing adaptations in terms of the number of participants, possibly to respond to the context of the research (Table 3).

Most studies used qualitative approaches (14/16). The method that prevailed in the research reviewed was the case study (9), which was used to systematically understand and interpret what happens with the pedagogical practices of teachers when they try to integrate technologies. The most frequently used instruments were: observation (8), understanding that it is an activity that is part of the operative nature of the LS, as well as interviews (5). Likewise, other

TABLE 1 Databases.

Database	Web of science	Scopus	Spinger link	Project central
# Of articles	4/8	10/10	3/12	5/41
1		Anci et al. (2021)		
2		Darsih et al. (2021)		
3	Hernández-Rodríguez et al. (2021)	Hernández-Rodríguez et al. (2021)		
4	Huang et al. (2021)	Huang et al. (2021)		
5	Joubert et al. (2020)	Joubert et al. (2020)	Joubert et al. (2020)	
6		Chatmaneerungcharoen (2019)		Chatmaneerungcharoen (2019)
7		Rochintaniawati et al. (2019)		
8		Paristiowati et al. (2020)		Paristiowati et al. (2020)
9		Zhou et al. (2017)		
10			González et al. (2021)	
11				Yildiz and Baltaci (2017)
12				Carpenter and Munshower (2020)
13				Danday and Monterola (2019)
14		Danday (2019)		
15	Marron and Coulter (2021)			
16			González et al. (2021)	

Source: Own elaboration.

TABLE 2 Countries where the research was carried out.

Country	Authors
Indonesia	Anci et al. (2021), Darsih et al. (2021), Paristiowati et al. (2020), Rochintaniawati et al. (2019)
Thailand	Chatmaneerungcharoen (2019)
Philippines	Danday (2019) and Danday and Monterola (2019)
Turkey	Yildiz and Baltaci (2017) and Kurt and Çakıroğlu (2018)
United States and Puerto Rico	Carpenter and Munshower (2020)
South Africa and Botswana	Joubert et al. (2020)
Canada	Zhou et al. (2017)
Puerto Rico	Hernández-Rodríguez et al. (2021) and González et al. (2021)
China	Huang et al. (2021)
Ireland	Marron and Coulter (2021)

Source: Own elaboration.

techniques found in the studies were recordings (7), reflective diaries (5), discussion groups (4), surveys (2), rubric and card classification. It is important to point out that within these qualitative studies, the use of form (3) was found to evaluate the TPACK proposed by Schmid et al. (2021). The results of multiple investigations show that the TPACK questionnaire can be considered a valid and reliable instrument to assess the TPACK of teachers (Schmid et al., 2021). In turn, all qualitative studies combine various techniques and instruments to capture the information necessary for their interpretation. The mixed-type investigations (2) combined quantitative and qualitative methods, descriptive methods (2) and quasi-experimental methods (2) were distinguished, which used forms and pretest-posttest tests (Table 5).

3.1. Theoretical understanding of TPACK

All the investigations take as reference the conceptualization of Mishra and Koehler (2006), Koehler and Mishra (2008), and Mishra et al. (2009). The TPACK is assumed to be the knowledge that the teacher needs to facilitate student learning of certain contents through pedagogical and technological approaches. Yildiz and Baltaci (2017) mention that the TPACK is a model that explains how teachers can incorporate technology into teaching and learning processes, as well as how to use technology more effectively and closer to pedagogical and content knowledge.

For their part, Danday (2019) and Danday and Monterola (2019) define TPACK as a domain of comprehensive knowledge about

TABLE 3 Educational levels.

Disciplinary scope	Educational levels					
	Preschool	Primary	Secondary	Half	Higher	Combination of levels
Sciences			Rochintaniawati et al. (2019) and Carpenter and Munshower (2020, p. 120)			Chatmaneerungcharoen (2019)
Mathematics		Huang et al. (2021, p. 4)	Yildiz and Baltaci (2017)		Kurt and Çakıroğlu (2018, p. 5)Hernández-Rodríguez et al. (2021, p. 4)González et al. (2021)	
Chemistry			Paristiowati et al. (2020) and Anci et al. (2021)			
Physical sciences					Danday (2019) and Danday and Monterola (2019, p. 18)	
English					Darsih et al. (2021)	
Combination						Joubert et al. (2020)
Physical education		Marron and Coulter (2021)				
Does not specify					Zhou et al. (2017)	

Source: Own elaboration.

TABLE 4 Overview of the participants.

Number of participants	Teachers in training	Teachers in service	Combination of teachers in training and in service
6		Anci et al. (2021)	
40		Chatmaneerungcharoen (2019)	
18	Danday (2019)		
3		(Darsih et al., 2021)	
52		Joubert et al. (2020)	
3	Paristiowati et al. (2020)		
12		Rochintaniawati et al. (2019)	
65	Zhou et al. (2017)		
120		Carpenter and Munshower (2020)	
18	(Danday and Monterola, 2019)		
5	Kurt and Çakıroğlu (2018)		
4	Hernández-Rodríguez et al. (2021)		
4		Huang et al. (2021)	
3		Yildiz and Baltaci (2017)	
They did not indicate	González et al. (2021)		
2	Marron and Coulter (2021)		

Source: Own elaboration.

didactic competence in three educational components: educational technology, method of instruction and subject matter. Joubert et al. (2020) understands TPACK as an integration of teaching strategy and content (PCK) with the support of technology (TK). In his study he uses reverse planning design to describe the implementation of TPACK. It integrates the base components of the PCK and the TK to look at the different decisions that the teacher makes. For their part, Marron and Coulter (2021) emphasize the importance of teachers assuming a critical position of technology, in order to use it from a particular pedagogical perspective.

Unlike the other studies, Zhou et al. (2017) and Kurt and Çakıroğlu (2018) identify with the holistic view of TPACK, where this construct is assumed as a process of understanding associated with the integration of technology, with pedagogy and the content of the subject. For these authors, the use of technology implies assessing the details that emerge in the interaction of the knowledge that is part of

TABLE 5 Methodologies.

Approaches	Authors	Techniques and instruments	Methods
Quantitative			
Qualitative	Yildiz and Baltaci (2017), Zhou et al. (2017), Kurt and Çakıroğlu (2018), Chatmaneerungcharoen (2019), Carpenter and Munshower (2020), Joubert et al. (2020), Paristiowati et al. (2020), Darsih et al. (2021), González et al. (2021), Hernández-Rodríguez et al. (2021), Huang et al. (2021), Marron and Coulter (2021)	(8) Remarks (7) Recordings (5) Interviews (Harris et al., 2012) (5) Journals of reflection. (4) Discussion group (3) TPACK questionnaires (Schmidt et al., 2009) (2) Survey Rubric Card sorting	(9) Case studies Interpretive-descriptive authentic research Descriptive
Mixed	Danday (2019), Rochintaniawati et al. (2019), and Danday and Monterola (2019)	(2) Pretest-posttest (2) Form (2) Interviews Daily Core Observation	(2) Descriptive (2) Quasi-experimental

Source: Own elaboration.

the TPACK, since in this way they can appreciate in a general and integrated way the actions of the teacher when incorporating technologies into teaching.

Most studies reveal the imperative relationship of the three basic bodies of knowledge of the TPACK (Mishra and Koehler, 2006): technological knowledge (TK), pedagogical knowledge (PK) and content knowledge (CK). These components allow a better understanding to organize and represent the contents to the students, the successful design of the classes with technologies and to understand the efficient way to integrate ICTs into the curriculum and teaching. The integrative vision is a consolidated theoretical perspective that has been used for the initial and continuous training of teachers, as well as from the pedagogical practice of different disciplines and educational levels. Similarly, most studies recognize the theoretical value provided by Shulman (1986, 1987) to the TPACK construct, from his conceptualization of PCK referring to the integration of pedagogical knowledge (how to teach) and content knowledge (what to teach).

On the other hand, the use of some theoretical notions of Niess (2005) located in the teaching of mathematics and focused on the development of courses for teachers oriented to the learning of different technologies, but also, in the analysis of the potentialities and limitations that derive from the use of technologies when teachers in training design classes or projects for a specific topic. Authors who have studies associated with research for the design of classes with technologies are also identified (Hsu et al., 2013; Mouza, 2016), conceptual analysis of technological pedagogical content knowledge (Archambault and Crippen, 2009; Cox and Graham, 2009; Ramos, 2016), evaluation of the TPACK in pre-service teachers of English (Öz, 2015), research on communication and educational technology (Spector et al., 2014), integration of educational technology in teaching (An and Reigeluth, 2011; Roblyer and Doering, 2014), the role of TPACK in case studies of preservice physics teachers (Srisawasdi, 2012), use of technology for critical thinking (Jonassen, 1996) Y students' rejection of the use of technology in teaching (Charbonneau, 2012), among others.

3.2. Lesson Study compression

Among the most representative authors in the theoretical development of the LS we find Fernández (2002), who describes the LS as a teacher training model that provides a variety of experiences that can improve the knowledge, skills and teaching habits of a student, collaborative, critical and reflective way. In addition, this author has studied the evolution of said model in the Japanese educational system, which has allowed him to promote a guiding protocol for researchers and academics to adequately work on the development of SL in the North American context and in other countries. We also find Lewis et al. (2009), which have been contributing reflections focused on refining the theoretical and methodological model of LS, so that it can respond to the cultural and social characteristics of the United States. Lewis et al. (2009) they define the category of LS as a collaborative learning system based on live guidance that uses four characteristics; research, planning, lesson research and reflection, essential to create changes in the knowledge and beliefs of teachers, the professional community and teaching.

3.3. Development of the TPACK

The literature reveals that the strategies commonly used for the development of the TPACK in teachers are associated with the use of learning approaches through class design, which consists of a collaborative work of teachers to build solutions to teaching and learning problems. a particular context (Koehler and Mishra, 2005). Under this perspective, LS can be located, which implies a series of cycles where teachers plan, observe, develop classes and reflect on their experiences (Fernández, 2002). Likewise, microteaching (MLS),

which is a strategy that is part of teacher training programs, generally implies that a teacher in training develops a class, which is normally recorded so that he and his classmates can see it and thus be able to reflect on it. her (Fernández, 2002). Finally, the study of microteaching, which is a combination of LS and microteaching (Zhang and Tang, 2021). These types of TPACK developments are part of studies that are supported by empirical evidence revealed, for example, by Harris (2016) in teachers in service and by Mouza (2016) in teachers in training, allowing the analysis of the training process. and professional development of teachers. Then, development of the TPACK is understood as all those actions that provide a learning context for teachers to transform their knowledge about teaching, content and technology into good pedagogical practices and improvement of professional skills.

Thus, research shows some particular adaptations and their effects. In this sense, Huang et al. (2021) called for a development of the TPACK through an online intercultural LS between China and Australia. It was based on the expansive learning theory to examine the progress of teachers through various activities. From this perspective, teachers showed improvement in their TPACK and TMK (mathematical technological knowledge) for the development of skills in the design of instructional tasks and the development of capacity in the use of various teaching materials and tools (physical devices and electronic, online resources). Likewise, Hernández-Rodríguez et al. (2021) formed online planning meetings with the purpose of determining the nature of the teachers' knowledge, and also, to examine the discussions associated with defining the didactic, technological and mathematical components of a class during the LS.

For their part, Kurt and Çakıroğlu (2018) organized a group of 5 participants to implement an experience based on MLS, the study consisted of the execution of a class to collect concrete evidence and thus verify the development of the TPACK of future mathematics teachers with Regarding the teaching of statistics through virtual manipulatives. In this same line, Zhou et al. (2017) point out that the MLS in the context of the development of the LS through courses, constitutes a promising way to develop the knowledge and skills of the TPACK in teachers in training. The importance of the MLS lies in the opportunity for practice, collaborative and instant reflection and mutual learning.

Rochintaniawati et al. (2019), Paristiowati et al. (2020), and Anci et al. (2021) implemented the LS to develop in TPACK in three stages that they named; plan, do and see. "Plan" is the stage in which teachers collaboratively build the lesson plan to be implemented. "Doing" in this stage is when a teacher develops teaching as a reference model and other teachers become observers of student learning. The "see" stage is the activity of reflection on the learning process, at this time the observers discuss and comment on the situations surrounding the student's learning process.

For their part, Yildiz and Baltaci (2017) set up an experience initially based on the informative phase and discussion in groups about a problem. Then three teachers carried out the planning and implementation phases of the class. Finally, the reflection on the learning was carried out within the framework of voice notes and observations. It is specifically pointed out how techno-pedagogical competences can be evidenced in a classroom environment both in the teacher's own practice and in that of his classmates during the development of the LS. On the other hand, Carpenter and Munshower (2020) show how the LS strategy impacts the methodological change of teachers through reflections on their teaching with technology, but they also refer to how teachers collaborate with their peers to generate new possibilities teaching.

Marron and Coulter (2021) intended to develop the TPACK using iPads to acquire and deepen new knowledge associated with the area of physical education through self-directed learning. They were based on the practice of the LS through four steps; (1) Analyze the curriculum and formulate goals, (2) Plan the lesson, (3) Conduct the lesson, (4) Reflect on the lesson and the planning process. These actors point out two imperative variables that influence the effectiveness of teachers for the integration of technology in teaching, therefore, they are part of self-directed learning; confidence (self-efficacy) and motivation (result expectations) (Niederhauser and Perkmen, 2010).

When comparing the results of the investigations, it can be concluded that all qualitative and mixed studies reported a positive effect on the development of the TPACK through the implementation of the LS. The sustenance of these experiences is based on collaborative and reflective spaces that allow an analytical and systematic view of the pedagogical practices of teachers when trying to incorporate technologies when planning, teaching and reflecting.

3.4. Difficulties

Rochintaniawati et al. (2019) point out that the course presented difficulties during the development of the first cycle of the LS since some schools in Indonesia managed a different school calendar, that is, while some schools had exams, others had vacations. Likewise, Zhou et al. (2017) recommends exploring the evaluation of the TPACK by means of a written test, since there is no research experience that examines the TPACK of teachers in training in this way. In addition, it was identified that there is a gap in the literature on studies that analyze the differential effects of a collaborative instructional planning approach that uses active and passive microteaching. Also, some assessments of the participating teachers are collected, the first mentioned: "The only negative thing I see with this approach is the time of the lesson, it is difficult to have an idea of how long these activities would take in a real class" (p. 99). The second indicated: "It is difficult to microteach as if you were in a room full of adolescents when in reality there is a room full of adults because we normally communicate with adolescents in a different way than we communicate with adults" (p. 99). The above evidences some concerns of some teachers, about their discomfort when teaching their peers as if they were school students, an aspect that Cabero and Martínez (2019) had already pointed out when considering how important the application of real problems should be for teachers in training processes.

4. Discussion

The exploration of the studies that develop the TPACK through the LS show the different ways of thinking about innovative training processes and focused on strengthening teachers' learning to teach with technologies from a critical and reflective perspective. Within this understanding, Fernandez's approach (2002) is distinguished, where he points out that a real pedagogical practice must be developed from the classroom, since it is a very powerful context to promote the

learning of teachers through the study of their praxis, and understand how students learn.

Now, making a specific analysis of the TPACK model, it is noted that the reviewed studies are mainly based on a TPACK associated with the integrative perspective (Mishra and Koehler, 2006), which is understood as an integrating body of PK-based knowledge, TK and CK that make up subcomponents; PCK, TCK, TPK, since these are formed as a consequence of the intersections between pedagogy and content (PCK), technology and content (TCK), and technology and pedagogy (TPK). According to the integrative view, these subcomponents are developed separately, but are integrated into the classroom during teaching. The preference found in the integrative TPACK can be attributed to the fact that most of the investigations tried to establish relationships between the different components that are immersed in the TPACK, since they can be perceived or contrasted in the different actions and moments of the LS; diagnosis, design, observation and reflection. This is how, it is identified that the PK component is developed more from the discussion and reflection scenarios, since they are intrinsic elements of pedagogy and *a priori* of the teacher's work.

For its part, the use of the LS to develop the TPACK in teachers in initial and continuing training were approached from courses and strategies to strengthen teaching, operationally 4 intrinsic transcendental moments of the LS are identified, among them are the delimitation of the situation to solve or the selection of a learning goal and exploration of concrete strategies to develop the class, then, the teachers begin to plan the class meticulously in group, obtaining planning as a product. Next, one of the group's teachers teaches the class while the other teachers observe the development and take notes on the different situations and, finally, the reflection on the process of planning and developing the class. These aspects are part of the actions of a LS cycle that converge with the theoretical narratives found in the literature (Pérez and Soto, 2015) and (Fernández, 2002).

Another aspect identified in the development of the LS in the studies, and which can be classified as a key variable that methodologically and pedagogically enriches the experience, is to have an expert who fulfills the functions of advisor, who closely follows the implementation to observe and guide the success of the experience with key recommendations. Rochintaniawati et al. (2019) point out the added value in terms of pedagogical experience provided by having an expert in the process as a participant.

On the other hand, in the methodological context of the studies that are part of this systematic review, a high preference was found for the qualitative approach, from which it can be inferred that this choice responds to the operative nature of the LS, since it requires a component of understanding and interpretation of the actions and attitudes of teachers based on the situations planned from this perspective. Although self-perception instruments are used (Schmidt et al., 2009), the look of the research goes beyond the concept that the teacher has of his training and his technological knowledge, it is more an exercise in interpreting the pedagogical task, understanding the decisions assumed by the teacher at different moments of teaching (Clark and Peterson, 1986).

The research methods were associated with the development of case studies that promoted training and professional development scenarios for teachers. Stake (2007) highlights its importance in the detailed study of the particular situations of a context, it is likely that the above was done with the assumption of achieving greater understanding and clarity of the planned situations, as well as facilitating the methodological operation of the LS. The description constituted an influential way for the analysis and systematization of the captured data, because it guided the understanding and interpretation of the realities of teachers when integrating technologies in teaching.

Under this scenario, the techniques and instruments identified in the study designs were; the TPACK questionnaire (Schmidt et al., 2009), observations, interviews (Harris et al., 2012), reflection diaries, recordings, discussion group, card classification, pretest-posttest and CoRe. The researchers took some that enjoy prestige and recognition within the TPACK theoretical corpus; TPACK questionnaires (Schmidt et al., 2009), observations and interviews (Harris et al., 2012). However, in all specific adaptations are denoted that respond to the particularities of the study, including the specific topic or subject.

On the other hand, the review of the literature reveals that there are specific subjects where studies combining the TPACK and LS categories have been focused; math, science, chemistry, physics and English. In fact, some combine different subjects within the same study according to the profiles of the teachers. There is evidence of a preference for the development of research in disciplines called "hard sciences," with a certain affinity with the "scientific method," which incorporate verification processes, rigorous and exact methods, which, in general, are part of the procedures or activities taught by teachers.

5. Conclusion

This systematic review has tried to make an approximation of the theoretical and methodological assumptions that have arisen in the studies that combine the TPACK and the LS worldwide. The results suggest insisting on the integrative perspective, as a set of knowledge that make up the TPACK (Mishra and Koehler, 2006). However, a distinction is made to focus the studies on specific knowledge about technology; TK, TPK, TCK and TPCK. On the other hand, scientific evidence shows that the qualitative approach has particularities that allow studying the various activities of teachers to understand and interpret knowledge (TPACK). Indeed, understanding and interpreting such activities implies the implementation of instruments such as observation and interview to capture data, discover connections and relate to other data sources in order to draw conclusions based on triangulations that validate the configured information.

In relation to the LS, the results show that there is no number of participants and specific space that limits the development of the cycles. Yildiz and Baltaci (2017) research revealed that the LS has been greatly modified compared to its initial structure. For these cases, technology becomes a great ally to develop the moments of the LS remotely, even granting greater capacity and flexibility for the analysis and study of the activities, as well as the evidence, since they are digitized and They can be seen as many times as necessary.

Within the limitations, it can be stated that studies in the Spanish language that combine the TPACK and LS models were not located, possibly because the highest percentage of this type of research is in English, although these two models are separately in the Spanish language show important steps in its development. Likewise, according to the nature of the investigation, a specific temporality associated with a cross-sectional investigation was established that limited a critical look at different periods assumed in this investigation.

It is important to point out that there are particularities that must continue to be explored in this type of research, for example; the role

of expert professionals and their true influence on the dynamics of the LS and the development of the TPACK, the researcher-teacher relationship, the prior awareness of teachers about the operation of the LS, to investigate how the changes they manifest are being systematized teachers in their pedagogical practice, and last but not least, the study of the divergent cultural and pedagogical implications of the Japanese context for the implementation of SL, which have been alerted by authors such as: Stigler and Hiebert (1999), Fernández (2002), Perry and Lewis (2008), and Rappleye and Komatsu (2017).

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

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Social robotics in music education: A systematic review

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Introduction: Social robotics applied to the educational context deals with proposals that start from the present to shape the future of what training in a specific subject can be. On this occasion, the aim is to investigate the connection between the utilization of social robots and the teaching–learning processes that take place within a formal music education environment at any stage of education.

Methods: To carry out this research, the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) model served as a reference to perform a systematic review of articles published in two of the most important scientific databases, Web of Science (WoS) and Scopus, since 2015.

Results: A total of four articles fulfilled the inclusion criteria.

Discussion: Our findings attest that social robotics still remains a practically unknown topic. Hardly any experiences have been developed in classrooms. In general, it is considered necessary for education, and more specifically for music, not to be left out of the developments in social robotics. This technology, which is increasingly present in various areas of our society, responds to the objective of defining the 21st century, and musical education is part of it.

KEYWORDS

artificial intelligence, music, educational technology, social robotics, systematic review

1. Introduction

Although the use of robotics in education can be described as an innovation, an extensive research base has already been generated around it (Lau et al., 2020; López-Belmonte et al., 2021; Arocena et al., 2022; Van den Heuvel et al., 2022). It is normal to think of experiences where students learn to design robots, thus developing their computational thinking (Acevedo-Borrega et al., 2022; Bati, 2022).

Nonetheless, the so-called "social robotics" has barely been implemented in the educational context as an innovative resource for the development of teaching–learning processes contextualized in today's society (Smakman et al., 2022). We must bear in mind that the latter is characterized as being technological, which highlights the need to address the exploitation of any possibility related to digital technology (Roig-Vila et al., 2021; Alonso Ruiz et al., 2022; Cabezas-González et al., 2022). In fact, even though some experiences associated with social robotics can be found in various fields (Lau et al., 2020; Gasteiger et al., 2021; Choukou et al., 2023), *a priori*, education does not seem to be one of them.

Social robotics, therefore, introduces as a new area that is working its way into the educational scenario by proposing to use robots as assistants for teaching. Despite certainly having a large potential, numerous technological and ethical challenges must also be faced to achieve a widespread utilization of these robots as effective teaching tools that can help to improve instruction at any educational level. In the short run, by considering some of the

research studies which have been undertaken (Azuar et al., 2019), the advantages brought by such robotic assistants mainly have to do with increasing students' wellbeing. Regardless of which type of improvement in students' overall training we may want to focus on, it would undoubtedly become interesting to directly examine experiences in which social robotics is used within a formal environment for the learning of a subject—Music, in our case.

We must not forget that music is not only regarded as an artistic teaching which beauty lies in its actual manifestation but also has proved beneficial in multiple aspects. By a way of example, concerning health, it enhances wellbeing and reduces stress; as for learning, music motivates students and predisposes them to learn other subjects (Chakraborty et al., 2021). Be that as it may, music teaching is essential for the comprehensive training of students. For this reason, any resource that we can use to offer new educational scenarios around music teaching will be welcome. In this case, our concerns revolve around the use of social robotics as an aid for this teaching, and it will be useful to know the research studies carried out in relation to this area so far.

Within this framework, a decision was made to carry out an analysis of bibliometric indicators which, according to García-Fernández et al. (2016), serves to study the degree of development achieved in a specific knowledge area. From a systematic review, the goal pursued with our study was to examine the educational experiences undertaken during the last few years with respect to the use of social robotics for music teaching inside a formal educational environment. Similar studies have been previously performed, such as the one authored by Lau et al. (2020), but that study had as its distinctive features the adoption of a scoping review format and the focus on the use of social robots in the treatment of children with diabetes.

The literature review proposed here consequently centers on searching for scientific articles listed on two databases: Web of Science (WoS) and Scopus. Its aim consists of providing a specific view of articles referring to experiences, programs, and actions where a social robot has acted as an assistant in music teaching. The results obtained will allow us to understand how things stand at present in relation to this topic.

To accomplish our purposes, this study is structured from a first section dedicated to the theoretical basis which starts with the most general aspects and subsequently deals with the most specific ones. Attention will be paid to the most relevant issues when it comes to social robotics, later focusing specifically on the key aspects of teaching as a whole, and more precisely music teaching, where the intervention of social robots comes into play. Because of all the aforementioned points, it will be possible to define more accurately the theoretical foundation which underpins this study.

Concerning methodology, the main postulates inherent to systematic literature review studies (Moreno et al., 2018; Higgins et al., 2021), especially those dictated by the PRISMA model, were followed. Hence, the references to inclusion and exclusion criteria, alongside data sources used and search strategies. Inclusion and exclusion criteria, data sources used and search strategies are presented. As for the results, attention will be paid to the characteristics of the music education experiences: the number of participants, the actors involved, the instruments used and the reported benefits. The article ends with a discussion and conclusion section. In short, we believe that this study can allow its readers to better understand the use of social robotics in the music classroom, thus helping to launch innovative proposals concerning music teaching in the technological society where we live.

1.1. Robotics in the educational context

The topic of robotics in the educational field is still relatively new, although the human–robot interaction (HRI) derived from its utilization already appears in numerous studies devoted to the achievements of robotics technology (Vlieghe, 2022). The experiences of learning with robots (Diago et al., 2018), as well as the development of the so-called computational thinking (Katai et al., 2021; Chiang et al., 2022; Christensen, 2022; Critten et al., 2022; de Carvalho et al., 2022; Huang and Qiao, 2022; Love et al., 2022), has led to identifying the potential of robots for their use as a new educational resource (Woo et al., 2021). It is what (Han and Jo, 2008), among others, call "robotic learning"—also shortened to "r-Learning."

This has eventually resulted in the concept of "educational robotics," a term that spans the different utilizations of robots within the formal educational context. On that basis, Gaudiello and Zibetti (2016)—quoted by Diago et al. (2018)—suggested three models for learning *via* educational robotics:

- "Learning robotics," where students use robots as a means to learn contents specific to robotics or engineering;
- "Learning with robotics," in which robots serve as the basis for the learning process; and
- "Learning by robotics," where students achieve a series of objectives in any subject by means of robotics.

In our opinion, this threefold classification must be complemented by the contributions made by Tanaka et al. (2015) about the use of robots in education. According to these authors, the presence of robotics within educational environments has generally adopted two main formats, respectively, based on seeing robots as an (i) educational material and (ii) educational agents. This last consideration seems especially important to us because social robotics—around which this study revolves—is framed within this approach.

With regard to the aforementioned studies, as highlighted by Tanaka et al. (2015), the expression "educational agent" refers not only to the robots that act as teachers or teaching assistants and have been designed to give instructions to students but also to those destined to support students' learning and study with them. In either case, they provide a social dimension that is lacking in other robots designed to initiate learners into robotics, programming, and electronics, such as Bee-Bot, Makeblock mBot, or Robo Wunderkind, to quote but a few.

1.2. Social robotics in the educational context

Social robots are seen as a technology that will gradually be integrated into every area of our society to provide us with assistance in numerous tasks. The robots are designed in such a way that they are able to socially interact with humans and thus simplify communication between human beings and machines, which, in turn, will increase their acceptance by users de Graaf and Allouch (2013). It is this characteristic of assistance and interaction with people that define a social robot as opposed to another type of robot. In addition, there are other characteristics such as humanoid appearance or human-like functions such as movement (Vlieghe, 2022). In this case,

the current challenge for artificial intelligence is for the social robot to interact in a natural way—i.e., the way we humans interact with each other. Han and Jo (2008) described one of the first experiences with a robot for electronic learning that was available in the world, and Rofi'ah et al. (2021) more recently showed a case in which dialogue was used for verbal communication with an assistant robot within a hospital environment.

Among the so-called "social robots" are humanoid robots—e.g., those whose appearance resembles that of humans. NAO and Pepper are the best-known models belonging to this group. NAO, a humanoid robot, developed between 2005 and 2007, and presented at RoboCup 2008, was innovative at its time, both for its functions and because it had great freedom of movement. This could be verified at the Shanghai Expo of 2010 when 20 NAO robots danced to Ravel's Bolero. In 2011, Aldebaran Robotics presented a new improved version, NAO Next Gen, with which the robot's control source code was released so that anyone could contribute to this project.

Pepper is a humanoid robot designed and developed by SoftBank Robotics Corp. and Aldebaran Robotics SAS (Tanaka et al., 2015). Conceived as an emotional robot, it can communicate with human beings in a wide range of areas through its autonomous behavior, speech, and the skills associated with the emotional recognition function. This robot forms part of a macroproject oriented to help creators and developers from all over the world to compile and store applications, as well as contents and smart technological components so that they can be shared. This makes it possible to enlarge Pepper's functions through the installation of new software and a set of applications known as "roboappli" (applications for robots), which is the main challenge for future investigations.

Pepper has been used in several domains, including the educational field. Thus, Tanaka et al. (2015) carried out a pilot test linked to English learning in which Pepper acted as an educational agent that learned with the participating children. They utilized three educational programs that the learners selected while interacting with the robot. In turn, Azuar et al. (2019) resorted to Pepper with the aim of modifying the evolution of a story according to the emotions detected in persons with intellectual disabilities. Similarly, Efstratiou et al. (2021) used Pepper to interact with children with an autism spectrum disorder in specially designed educational scenarios about monetary transactions. All these scenarios pursued to boost short- and long-term memory, alongside communicative and social skills, through exercises with coins and notes.

Another experience with Pepper was the study undertaken by Ujike et al. (2019), contextualized in Japan, where humanoid robots have entered the medical environment as well as that of seniors' care. Their experience revolved around the implementation of a 40-min body–brain gymnastics recreation program adapted to the functional level of older adults. It consisted in moving, looking/curing, and playing. The exercise "move the body" and other active drills within the motion range were performed in conjunction with the music. In fact, when Pepper-CPGE was used, the following changes took place: the level of communication between patients and nurses during rehabilitation care increased; patients showed an interactive and committed attitude, actively participating in the attention prevention gymnastic exercises too, using Pepper-CPGE; patients had fun and enjoyed talking to Pepper-CPGE.

1.3. Robotics and music

Research into robotics and music is enjoying a boom (Cádiz et al., 2021) in the broad field of music research (Ilari, 2020). "Robotic music" focuses on developing the intelligence of machines, in terms of algorithms and cognitive models, with the aim of capturing the underlying principles of music perception, composition, and playing (Chakraborty et al., 2021). The ability of robots to manifest music in an artistically expressive manner, like that of humans, lies in a multidisciplinary field between engineering, computing, music, and sociology. The aspects being investigated include the musical robot and the human–robot interaction linked to new forms of creativity, exchange, and playing.

By way of example, Savery et al. (2021) analyzed the musician's interaction with the robot before and after the performance, as well as between pieces. According to these scholars, these tasks involving a non-musical interaction, such as the presence of a robot during the configuration of the musical team, play a key role in the robot's human perception. Another case of an experience shared by robots and humans can be found in Vear (2021), whose investigation centered on technical solutions and the artistic potential of artificial-intelligence-driven robots that co-create with a human musician who improvises (the author) in real time. Similarly, Chakraborty et al. (2021) delved deeper into one of the characteristics of musical performances in which musicians do not play rigidly, but play, move, and behave depending on the "feeling" of the music, and in tandem or according to non-verbal mutual gestures between them or from the main conductor. All of this requires an advanced level of cognitive operation for musical robots within such interactive, synchronized, and collaborative environments.

As for social robots and music, it is worth mentioning the study of Ribes et al. (2016) on performance. This time, the humanoid robot iCub listened to the human performance and subsequently learned on an incremental basis by means of imitation. This possibility of using the robot as a performer has been addressed in numerous studies. For instance, Fei et al. (2019) showed how a robot played an instrument called a dulcimer with a self-learning method whose training relied on data associated with three types of information: the tone of the adjacent notes, the time interval in a musical piece, and the decision results in the real processes of performance by human beings.

Scimeca et al. (2020), in turn, utilized a minimalist experimental platform based on a robotic arm equipped with a single elastic finger to examine on a systematic basis both motor control and the outcome resulting from piano sounds. Miller (2020) experimented with robots that played live neoclassical jazz combined with free improvisation. Finally, the study undertaken by Krzyżaniak (2020) resorted to swarms of autonomous musical robots for the purpose of analyzing human–robot and robot–robot interaction—e.g., when musical robots listen to, learn from, and respond to each other while improvising music together.

1.4. Robotics and music applied to education and other fields

Music and robotics make up a duo that is used in plenty of fields. Thus, from a perspective linked to health (music therapy), the

utilization of robots provides a variety of possibilities. By way of example, Zhang et al. (2022) describe an experience that has to do with musical perception through gestural robotics. More precisely, they deal with a therapy of musical perception for autistic children that uses interactive gesture-controlled robots supported by the concept of educational psychology and deep learning technology.

Specifically in the educational context, robotics and music are addressed to connect them with other subjects. Thus, Torrejón Marín and Ventura-Campos, 2019 dealt with educational robotics in music teaching, in combination with mathematics. They used Bee-Bot robots with 3–7-year-old students who programmed the former so that they could move along boards and study with the musical contents proposed. In this way, they developed students' logical-mathematical thinking and increased their motivation. Already-designed robots that help in learning other subjects may be utilized too. An example thereof is the experience carried out by Marques de Andrade et al., 2018, who created a robot for musical keyboards with the aim of providing more creative and interactive educational activities associated with physics teaching.

Park et al. (2015), in turn, pursued to develop a kind of robot-based learning with programming meant to improve students' creativity and understand satisfaction in primary education classrooms. An instruction strategy was followed in this analysis that helped students to express learning contents about the Korean language, mathematics, and music in the movement of the educational robot with scratch-type programming so that learners could program the robot.

For their part, Chou and Chu (2017) proposed a percussion learning device that brings together tablets and robots and consists of two systems: one for the teaching of rhythms in which users can compose and practice rhythms using a tablet, and another for robot execution. First, the teachers type the rhythm training contents on the tablet. Then, the students do these percussion drills with a tablet and a small drumkit. The teaching system provides a new, easy-to-use score edition interface to compose a rhythm exercise. It additionally supplies a rhythm classification function that makes children's percussion training easier and improves beat stability. Seeking to encourage learners to practice with percussion drills, a robotic action system is utilized to interact with the children which can perform percussion exercises so that learners can listen to them, subsequently helping the former to practice the exercise in question.

It must be remembered, however, that although evidence exists of the benefits that the use of robots can have in the educational context as a whole and particularly in the music area, no systematic reviews or meta-analyses seem to be available that allow us to study the experiences developed—more precisely regarding music teaching within a formal educational environment. In view of all the aforementioned points, it seems appropriate to undertake a systematic review of the educational experiences undertaken and their specific effects on the teaching–learning process. This will make it possible to ascertain some common aspects in the development of such processes, thus providing guidance for future experiences.

1.5. General objective and research questions

Based on all the considerations made so far, the following research questions can be posed:

- What educational experiences have been carried out in the formal context of music teaching from the use of social robots in the classroom?
- What are the characteristics of these educational experiences?
- Do the results of the identified research studies support more widespread use of robots in the music classroom?

The general objective of this study will consequently be to check the current level of knowledge about the utilization of social robots within the educational domain of music teaching. From this, general objectives are drawn and the three specific objectives are listed as follows:

- To identify the educational experiences in music teaching with social robots from a systematic review of the scientific literature contained in selected databases since 2015.
- To analyze the implementation of educational experiences in music teaching with social robots and their main features.
- To examine the evaluation performed in the educational experiences of music teaching with social robots.

Based on all the aforementioned points, and within the framework of a systematic review, the following hypothesis is launched: the use of social robots in formal music teaching has beneficial effects on students' learning.

2. Method

2.1. Type of study. Design

A systematic literature review (Conn et al., 2003; O'Connor et al., 2008; Higgins and Green, 2012) was performed for the purpose of analyzing the most outstanding studies published in relation to the suggested research questions. This eventually enabled us to create a database with the selected sample, as recommended by Prendes-Espinosa et al. (2020). The study of this scientific review was approached "from descriptive and content analysis techniques" (Rivero et al., 2019) and took into account the previously formulated research questions. It was performed in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) guidelines (Liberati et al., 2009; Moher et al., 2009; Tacconelli, 2010) in an attempt to carry out research as systematically as possible and accordingly provide guarantees for the whole procedure implemented from the defined methodological guidelines. As pointed out by Moher et al. (2009), PRISMA can serve as the basis to undertake systematic reviews of various fields, even though some modifications will have to be made—depending on each case—in the flow diagram and the verification list (the elements that permit to organize and structure the research process). In this case, we specifically refer to the items utilized in PRISMA's standard verification list (Liberati et al., 2009; Urrútia and Bonfill, 2010): title, structured abstract, justification, objectives, protocol and recording, eligibility criteria, information sources, search, data compilation process, data list, risk of bias between studies, selection of studies, characteristics of studies, evidence summary, and limitations and conclusions.

2.2. Procedure

The requirements specified at the "Reglamento del Comité de Ética de la Investigación de la Universidad de Alicante" (Regulations of the Research Ethics Committee of the University of Alicante; BOUA, 2022) were followed at all times. Similarly, the procedure entailed going through a number of stages typical of systematic-review-based research studies, which are summarized as follows:

- Formulation of the problem to be examined: the first step is carried out by taking as a reference the research questions and objectives mentioned earlier. It is important to note that, before starting this research, we checked on the PROSPERO database[1] that no reviews concerning these issues existed; the fact that it was a new study undertaken within the framework of a University Master's Degree made us decide not to send this protocol to PROSPERO.
- Search for relevant studies from a set of sources and parameters suited to our research. To that end, we chose to use two of the most important scientific databases that will be specified in the following sections. Furthermore, several parameters were established that served to delimit the systematic review, namely the inclusion and exclusion criteria, based on which we carried out the literature search with the aim of selecting the studies that fulfilled such criteria. It needs to be highlighted that we had to make a number of changes in the process during this stage. Those changes were explicitly stated, together with their justification, to provide evidence that the results had by no means been affected by potential biases.
- Sample analysis: From the studies that complied with the respective inclusion criteria, the corresponding description and coding were carried out, which, in turn, allowed us to show the results.
- Interpretation: Taking into account both the results derived from coding and the objectives set, attention was paid to the consequent discussion as well as to drawing a conclusion.

2.3. Inclusion criteria

Following Prendes-Espinosa et al. (2020), "the criteria were: inclusion and exclusion, relevance, validity of studies, data description, removal of duplications, bias risk, application of Boolean operators and bilingual descriptors" (p. 11), in addition to implementing "the PICoS (population, phenomenon of interest, context, and study design) strategy" (p. 12). This makes it possible to identify and structure terms, which are relevant for searches (Martínez Díaz et al., 2016; Morris et al., 2021). More precisely, these were the inclusion criteria used in this systematic review as follows:

- With respect to the population:
  - o Time specification: A decision to analyze the period 2015–2022 was made for the purpose of extracting the most recent studies devoted to the research problem under study.
  - o The descriptive terms acceptable for the population had to contemplate the terminology referred to as social robotics and music.
  - o Type of document: articles.
  - o Access: open.
  - o Source: journal.
  - o Area(s): all.
  - o Publication language: English and Spanish.
- Concerning the phenomenon of interest: our study focused on experiences related to the use of social robotics in the music classroom. Hence, our decision to select only those studies which directly address this topic with programs, activities, experiences, and projects along those lines. For that reason, attention will exclusively be paid to their presence in the title, the abstract, or the keywords of the articles to be analyzed.
- Regarding context: the research concerned any educational level and referred to a formal environment.
- As for the design of the research study applied to investigate the corresponding experiences, all methods were admissible, including the case study, which we finally decided to include despite not having considered it at first due to the shortage of results obtained. Not only quantitative studies but also qualitative and mixed ones were selected, similarly contemplating longitudinal as well as individual research studies. With regard to evaluation tools for variable measurement, all of them were included regardless of whether they had a qualitative or quantitative nature, such as self-reports, *ad hoc* tests, validated tests, and interviews. In terms of results, all options and formats dealing with the benefits derived from the experience developed were considered.

Similarly, these inclusion criteria define the exclusion criteria. Thus, concerning the type of experience, we found publications about studies devoted to music and robotics in non-formal contexts (e.g., a performance), which were not taken into account.

2.4. Search strategy

2.4.1. Databases and descriptors

Using the design described earlier as a reference, the relevant records were identified from systematic reviews on the following electronic databases: Web of Science: Web of Science Core Collection [Social Sciences Citation Index (SSCI)], Emerging Sources Citation Index (ESCI), Science Citation Index Expanded (SCI-EXPA), and Scopus.

The same descriptors and parameters were used for the advanced search in the aforementioned databases, Boolean operators, and actions being adjusted on the same universe; in this case they were the title, abstract, and keywords. Table 1 lists the descriptors used from the semantic families.

To avoid fugitive literature from the WoS and Scopus databases and following the indications of Pedraza-Navarro and Sánchez-Serrano (2022), a search was performed in other databases, but no

1 https://www.crd.york.ac.uk/prospero/#searchadvanced

new contributions to the results were located. Specifically, the sources consulted are indicated later and, in parentheses, the number of publications located according to the inclusion criteria used: Dialnet (4), ERIC (1), ProQuest (12), and DOAJ (34). After examining the articles, none of them alluded to the object of study of the present investigation, so they could not be added to the results.

2.4.2. Selection process

Although searches took place between February and April, the results were updated on 25 May 2022. A decision was made to apply the same search strategies to each and every database. More specifically, all three semantic families were included in the title, abstract, or keywords so that we could exactly replicate the search performed.

It deserves to be highlighted that in SCOPUS, we proceeded to filter the initial outcome—532 results—using the tools available on the interface of that database; or expressed differently, the search was confined to a series of filters (see Table 2). The result obtained in that way was 40 articles that we exported to our Mendeley account.

As for WoS, we initially achieved 193 results. Once again, we proceeded to filter those results using the filters specific to the WoS interface (see Table 1), thus reducing the number to 29 results. The outcome of these searches shaped the corpus, with the emphasis being placed on removing duplications, examining all the titles and abstracts, and, finally, discarding those articles which were not of interest to us according to the inclusion and exclusion criteria.

Both the flow diagram and the information results obtained through the selection and review process are shown in accordance with the scheme proposed in PRISMA (Urrútia and Bonfill, 2010) and following the PICoS strategy (see Figure 1). A first descriptor-based search led to an initial population of 725 documents—with the following distribution by databases: Scopus: 532 and WoS: 193. After filtering or sifting in accordance with the previously specified inclusion criteria, the final sample contained 69 documents. Both the abstracts and/or the full texts of the remaining articles were examined to ascertain which of them fulfilled all the inclusion criteria—duplications were eliminated. A total of four were eventually selected, which provided us with a final sample of records to carry out the process of extraction of the data needed for the corresponding analysis. With that aim in mind, Microsoft Excel was utilized to add information on the basis of the coding and the information related to the sample's descriptive data.

2.4.3. Databases and descriptors

From the search undertaken on the aforesaid databases, and taking into account all the inclusion and eligibility criteria, the final sample of studies selected in this systematic review contained four scientific articles (see Table 3), in view of which a search was carried out on another database with the aim of ensuring that the result reflected the existing literature on this topic. We thus performed the same search on EBSCO, the initial outcome being zero articles.

Our analysis of the sample under study began with the examination of the descriptive characteristics of the selected articles. To this end, we analyzed them from a series of variables: time distribution (year of publication), the scientific journal where it was published, and authorship (see Table 4).

Similarly, we performed a content or semantic analysis, which required coding the articles based on a set of variables related to the corresponding experiences with social robots. The three main categories refer to (a) the population to which the experience is addressed, (b) the characteristics of that experience, and (c) the design of the research undertaken around the experience in question.

As for the population, an analysis was carried out about the participants' sociodemographic data, such as geographical location, age, gender, and the specific features of the target group in this experience. In relation to the characteristics of the latter, our attention focused on its motivation and objectives, as well as its duration and the musical aspects covered. We finally examined the evaluation of experiences, if any—an aspect analyzed too—method utilized, tools used for the evaluation, and the results thereof.

Finally, it is worth highlighting that this coding of records was performed in accordance with a series of categories which, despite having been defined beforehand, were updated gradually as we coded each article. This allowed us to identify the key topics and the most frequently used concepts, accordingly making it possible to carry out an in-depth study about the contents of the articles from a set of codes (see Table 5).

TABLE 1 List of descriptors used in the systematic review.

1	2	3
("Humanoid Robot*" OR robot* OR "Social robot*" OR "Human-looking robot*" OR "Robot* assist*" OR "Soft Robot*" OR Telerobot* OR "Child-robot interact*" OR "Human-robot interact*" OR "Remote robot*" OR "Affective robot*" OR "Autonomous social robot*" OR "Social assistive robot*" OR "Robot* systems" OR "SMART systems")	Music*	(Education* OR learn* OR teach*)

TABLE 2 Filters used in the systematic review.

SCOPUS	WOS
Language source: journal type of document: article years: since 2015 (inclusive) Access: open	Open access
	Since 2015
	Type: articles

3. Results

3.1. Identification of educational experiences with social robots in music

3.1.1. Population

Regarding geographical location, the development of the respective educational experiences was evenly distributed between Netherlands and Iran. To structure the sample results, the samples

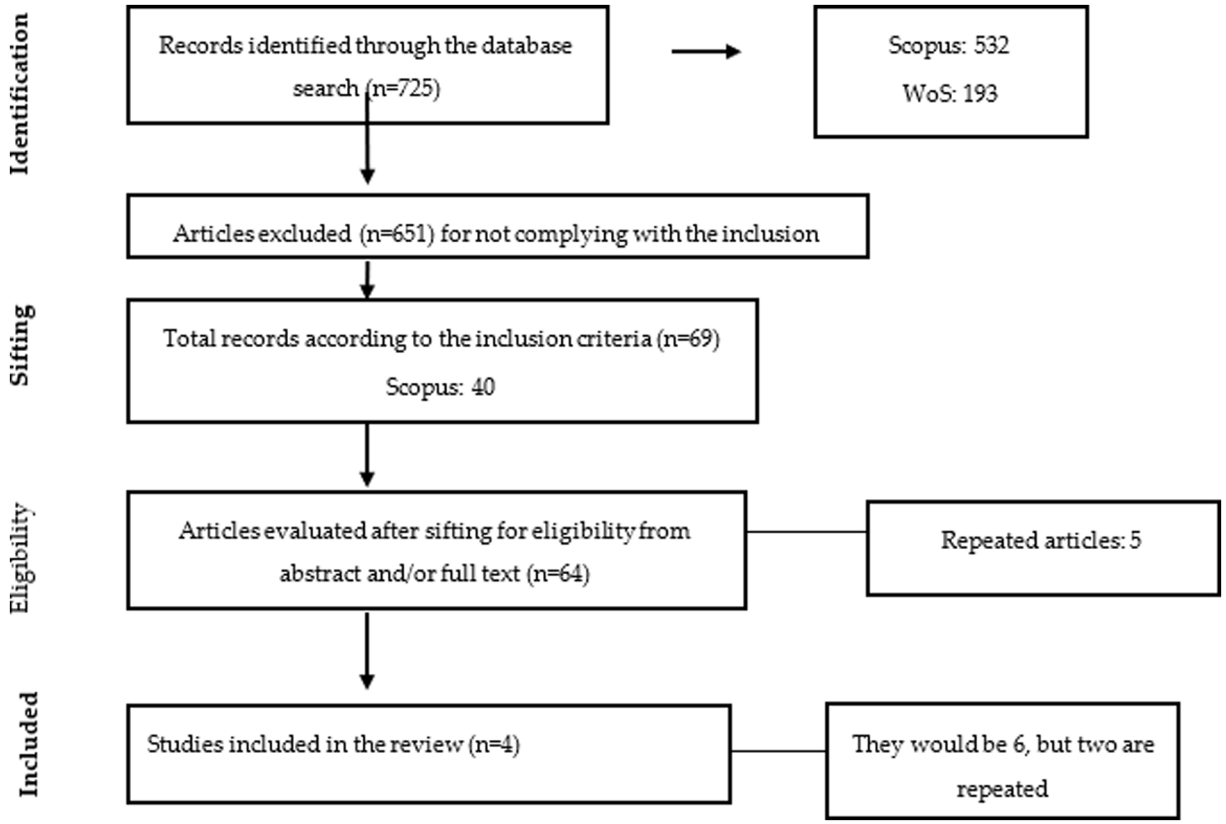

FIGURE 1
Flow diagram used [elaborated by the authors from a template developed by Moher et al. (2009)].

TABLE 3 Selected articles.

Final result of article selection:
Taheri, A., Meghdari, A., Alemi, M., & Pouretemad, H. (2019). Teaching music to children with autism: A social robotics challenge. *Scientia Iranica*, *26* (Special Issue on: Socio-Cognitive Engineering), 40–58. 10.24200/sci.2017.4608
Taheri, A., Shariati, A., Heidari, R., Shahab, M., Alemi, M., & Meghdari, A. (2021). Impacts of using a social robot to teach music to children with low-functioning autism. *Paladyn, Journal of Behavioral Robotics, 12*(1), 256–275. https://doi.org/10.1515/pjbr-2021-0018
Song, H., Barakova, E. I., Markopoulos, P., & Ham, J. (2021). Personalizing HRI in musical instrument practicing: the influence of robot roles (evaluative versus nonevaluative) on the child's motivation for children in different learning stages. *Frontiers in Robotics and AI*, *8*: 699524. https://doi.org/10.3389/frobt.2021.699524
Smakman, M. H. J., Preciado Vanegas, D. F., Smit K., Leewis, S., Okkerse, J., Obbes, J., Uffing, T., Soliman, M., van der Krogt, T., y Tönjes, L. (2022). Robot buddy for primary school children. multimodal technologies and interaction, *6*(4): 29. https://doi.org/10.3390/mti6040029

were grouped by intervals: <25, 26–50, 51–75, 76–100, and >100. More specifically, there are two experiences with four infants (Taheri et al., 2019, 2021). In both cases, they involved children diagnosed with ASD. In the 2019 experience, the authors highlighted that the children had no previous music learning background, they were able to understand/obey instructions, they had a minimum cognitive development of a 3-year-old child, and they could perform simple imitation movements. In addition, hey highlighted that two were excluded: one because he became frightened on the first day and the other due to problems between his parents. Song et al. (2021) worked with 31 children and Smakman et al. (2022) with 115 children.

In relation to the age variable, Taheri et al. (2019) established a minimum of 3.5 years; Taheri et al. (2021) situated it between 5 years and 1 month and 6 years and 5 months; and Song et al. (2021), between 9 and 12 years. In this last case, the participants were piano students—the other studies did not involve learners from music subjects. As for their level of expertise, children were divided into three different groups by learning stages (number of years studying piano) following the piano teachers' suggestion, namely, beginners (less than 2 years, $n = 11$), developing musicians (between 2 and 4 years, $n = 10$), and advanced performers (over 4 years, $n = 10$). In turn, the experience described by Smakman et al. (2022) included two experiments about confidence between 4 and 6 years and stress between 3 and 6 years.

Regarding gender, no rules are repeated for this variable. In Taheri et al. (2019), all participants were boys; in Taheri et al. (2021), one girl and three boys took part; the study performed by Song et al. (2021) involved 15 girls and 16 boys, and that of Smakman et al. (2022), 26 boys and 29 girls in the experiment about confidence, and 30 boys and 30 girls in the experiment about stress.

3.1.2. Main aspects of the experience

3.1.2.1. Motivation or objectives of the intervention

Our approach to the reasons for—and the goals sought with—the implementation of the different experiences can be summarized

around three areas: attention to special educational needs, the teaching of musical instruments, and human–robot interaction.

Thus, Taheri et al. (2019) set themselves the aim of teaching music to children with autism with two specific objectives: (1) to familiarize these learners with the foundations of music using a robot that played the xylophone and the drumkit as a teacher's assistant, and (2) to improve the social and cognitive skills of those children with autism by means of active music games. Three questions served as the starting point for Taheri et al. (2021): (a) Does a humanoid robot acting as a teacher's assistant have the ability to teach musical rhythms and notes to low-functioning autistic children? (b) Does robot-assisted music-based education impact on the social and cognitive skills of low-functioning autistic children? and (c) Can robot-assisted interventions affect the stress levels of low-functioning participants' parents during music education classes?

Finally, Song et al. (2021) investigated whether or not children at different learning stages would have higher motivation when assisted by a robot playing various support roles: evaluative vs. non-evaluative role. They formulated the following research question: Can the different roles of robots (i.e., the evaluative role and the non-evaluative one) differently influence the motivation of children at various learning stages when practicing with instruments? Smakman et al. (2022) adopted a similar approach for the purpose of exploring children's confidence with social robots, to which they added a second experiment focused on reducing their stress levels through the utilization of a social robot.

3.1.2.2. Duration

None of the experiences entailed a high number of sessions. The two experiences provided by Taheri et al. (2019, 2021) present the same sequence, with hardly any variations: there were two initial sessions without robot-assisted music teaching (week 1). Week 2 included a pre-test before introducing the robot in the guidance session. In total, nine sessions (between weeks 3 and 11) were followed, with interventions for each child. A post-test was carried out in the last session (i.e., week 11), and the follow-up test was 4 weeks later. Song et al. (2021) contemplated three sessions: the child practicing alone, assisted by the evaluative robot, or assisted by the non-evaluative robot (in a random order).

3.1.2.3. Robot used

In general, 50% of experiences utilized NAO H-21 (Taheri et al., 2019, 2021) while 25% resorted to SAMBuddy Storytelling Cuddle, a robot resembling a cuddly toy full of very basic hardware components (Smakman et al., 2022). Only in one case was a robot created *ad hoc* for the study; Song et al. (2021) presented a robot with two roles: evaluative ("categorical specific language, praising effort, with a slow, constant tone, and a calm facial expression, centering on practice, moving little, and dressing formally (that is, shirt)"); and non-evaluative ("indirect abstract language, praising talent, with a fast active tone and a funny facial expression, moving a lot and dressing informally (i.e., striped jersey)").

3.1.2.4. Musical content covered in the experience

Learning to play a musical instrument was present in 75% of cases. Two experiences—carried out by the same research group (Taheri et al., 2019, 2021)—utilized the robot so that participants could learn to play a real drum/xylophone in robot–child or robot–child–therapist–parent imitation games; in turn, the children who took part in the study of Song et al. (2021), played the piano. Instead, the robot was used by Smakman et al. (2022) as an alternative activity to human beings listening to classical music, ultimately seeking to reduce stress. On this occasion, a child–robot interaction or a conventional music intervention—one of the interviewers playing the classic song "Comptine d'un autre été (Amélie)"—took place in separate rooms.

3.1.3. Evaluation of educational experiences with social robots in music

3.1.3.1. Evaluation method

We should ask ourselves whether or not these experiences have been evaluated and how. All of them (100%) are case studies. Regarding evaluation tools, Song et al. (2021) utilized the Situational Motivation Scale to measure four (motivation) dimensions: autonomy, pleasure, stress, and interest. Taheri et al. (2019) worked with three types of measurement tools, namely: evaluations toward the child of the kind "hit the drum and/or the xylophone using sticks." The evaluations were performed by an expert in autism and a music teacher, both of them psychologists. They also used interviews with parents as well as three questionnaires validated in research on autism: the Gilliam Autism Rating Scale (GARS), used to estimate autism

TABLE 4 Descriptive characteristics of articles.

Descriptive characteristics of papers	
1.1.	Time distribution (year of publication: 2015-2022)
1.2.	Scientific journal where it was published
1.3.	Authorship

TABLE 5 Codes used to analyze the contents of articles.

Codes used					
1. Population		2. Characteristics of the experience		3. Evaluation of experiences	
1.1.	Geographical location				
1.2.	Sample size	2.1.	Motivation or objectives of the experience	3.1.	Evaluation method
1.3.	Age	2.2.	Musical aspects covered	3.2.	Results of experiences
1.4.	Gender	2.3.	Structure of the experience	3.3.	Guidelines to improve music teaching
1.5.	Specific characteristics of the target group in the experience	2.4.	Duration		

severity; Autism Social Skills Profile (ASSP) on the social behaviors of a 6–17-year-old individual with autism; and Parenting Stress Index-Short Form (PSI-SF) about parents' stress.

Taheri et al. (2021) evaluated imitation and social communication skills, alongside regular imitation exercises, and the ability to reproduce rhythm. They used four questionnaires too, including the Autism Social Skills Profile, Gilliam Autism Rating Scale, Autism Verification List, and Parenting Stress Index-Short Form. Song et al. (2021) assessed motivation by means of a questionnaire and video data analysis. As for Smakman et al. (2022), they resorted to a questionnaire—before the interaction—about sociodemographic data and others related to age, grade, and gender, in which interviewees were similarly asked if they had ever seen a robot before; and if they had, they were expected to describe their previous experiences with them. Furthermore, they used an *ad hoc* prepared questionnaire adapted to the participating children to ascertain their state of mind and level of stress after the experiment; a research assistant carried out observations using an intervention monitoring scheme (robot and music).

3.1.3.2. Results of experiences

The outcome of the diverse interventions allowed us to verify that improvements concerning the objectives set had been achieved in all of them, although the difference was not significant in one case. As pointed out by Taheri et al. (2019), the robot NAO was able to teach notes/rhythms, parents' stress decreased during sessions, and there were remarkable improvements in subjects' social/cognitive skills. In their subsequent experience (2021), the children could not pass a test on music notes or the reading of musical phrases due to their cognitive deficit. However, they showed acceptable improvements in the Stambak Rhythm Reproduction Test, which means that some rhythm learning did occur.

The findings of Song et al. (2021) revealed a significant interaction between the conditions (i.e., alone, evaluative robot, and non-evaluative one) and the learning stage groups, which suggests that children belonging to groups situated at different learning stages have different levels of motivation when they practice on their own or with an evaluative or a non-evaluative robot. More specifically, the authors observed that beginners showed greater persistence when practicing with the non-evaluative robot, whereas advanced players expressed higher motivation after practicing with a robot than when doing so alone, though no differences appeared between the two robot roles. The exploratory results also pointed to the possibility of gender having an effect on interaction with robot roles in children's motivation during music practice with social robots.

Smakman et al. (2022) found that, regardless of the robotic characteristics assessed (intonation, male/female voice, and humor), most children tend to trust a robot during their first interaction. Curiously enough, adding humor to robots' dialogues seems to impact negatively on the confidence of children, especially when it comes to those who have had no previous experience with robots. It was in this experience that the comparison between a conventional music session and the interaction of a social robot revealed no outstanding differences. Both interventions managed to reduce children's stress levels, albeit not to a significant extent.

4. Discussion and conclusion

This research aimed to review the scientific literature devoted to formal educational experiences where social robotics has been utilized in music teaching. From this general objective, a number of research questions were posed. Regarding the first question about which educational experiences have been undertaken through the use of social robots in classrooms, our study relied on a systematic review of the scientific literature since 2015 on two of the most important databases available in the educational context: WoS and Scopus. In relation to this question, and following the PRISMA model guidelines, 69 studies were located—65 after removing duplications. Faced with such a small number, the titles, abstract, and/or full texts were directly reviewed to confirm that they referred to the topic under analysis in accordance with the inclusion and eligibility criteria. This left us with four, all of which fulfilled the inclusion criteria.

In this way, we could establish which articles were going to be reviewed. As can be seen, it was not a large sample; however, this result matched that of other similar studies, such as those authored by Rosili et al. (2021) and Lau et al. (2020). Thus, the selected studies were Taheri et al. (2019, 2021), Song et al. (2021), and Smakman et al. (2022).

Concerning the second question, which referred to the specific characteristics of these educational experiences, a description was carried out of the articles that made up our sample according to their time distribution, the scientific journal in which they had been published, and their authorship; these aspects were already considered by other authors in their respective systematic reviews (Prendes-Espinosa et al., 2020). It deserves to be highlighted that, contrary to our expectations, we failed to obtain an upward evolution of publications, especially because of the increasingly advanced technological environment where we live. On the whole, we agree with Han and Jo (2008) that a need exists to investigate the topic around which this study revolves. We are surrounded by technology and social robotics arises as an expanding field. Hence, the usefulness of localized studies is to analyze the scientific evidence available and look for strengths and weaknesses in the corresponding experiences. Due to this, tests with robots in the music classroom can gradually adapt to the specific needs of each discipline and accordingly become an integrated, reality-based teaching format.

On the other hand, it should be noted that in the selected educational experiences the "social" value of the robot used stands out. In concurrence with other research (Azuar et al., 2019), the wellbeing of the students is improved by the characteristics of these robots. The appearance of the robots used, similar to that of humans, and the type of programming, which allows the interpretation of certain social behaviors, contribute to this objective. As found in other studies (de Graaf and Allouch, 2013; Park et al., 2015; Efstratiou et al., 2021), there is an increase in the motivation of users—in our case, children in a musical learning context.

Delving into other characteristics of any educational experience, such as the role of the educational community and the collaboration of families, it should be noted that these variables have not been considered in the studies found. In general, families appear involved in studies referring to social robots when these are used as support in the home (Gasteiger et al., 2021; Choukou et al., 2023).

As for the third and last question on whether the results of the identified research studies support a more widespread utilization of robots in the music classroom, an affirmative answer can be inferred. Thus, as highlighted by Taheri et al. (2019), the progress achieved in this preliminary exploratory study confirmed the potential benefits

derived from using social robots and smart technologies as facilitators in music teaching and cognitive rehabilitation. However, some reviews highlight that robots are rarely implemented for long periods of time in the classroom (Woo et al., 2021). This precludes securing the potential advantages of using robotics in music and other related areas.

Similarly, to give a more detailed answer to this question, we analyzed each experience described in the respective articles based on the coding designed. More precisely, attention was paid to various aspects referred to the population, such as sample, gender, and geographical location. At this point, it is important to highlight the disparity with regard to the characteristics of the target population: sometimes students with certain psychosocial features, and on other occasions, students enrolled in music subjects. Therefore, we could not define a common reference framework for the target population, which is not the case for other topics related to social robotics in the educational context, such as care for people with autism spectrum disorder, a topic widely addressed in the scientific literature (Woo et al., 2021; Zhang et al., 2022).

As regards the objectives of the respective experiences, they were analyzed and proved to respond to the needs and interests of students who receive music teaching, both in terms of learning to play musical instruments and listening to classical music. As for the number of participants, it was not high, as happens in most of the studies about social robotics (Lau et al., 2020).

An aspect worth highlighting is that we analyzed the evaluation of experiences seeking to find evidence of the possible advantages brought by the utilization of robotics in music. With this aim in mind, coding was performed in accordance with the following codes: evaluation method, results of interventions, and benefits derived from them. In every article, the diverse case studies added high value in regard to the direct and indirect link between music and school.

After the findings were obtained and the discussion was carried out, it becomes necessary to state that the working hypothesis that we formulated has been confirmed in light of the results already explained earlier. Furthermore, the four experiences examined suggest that the use of social robots in formal music teaching benefits children's learning, an aspect that coincides with previous studies referring, in general, to the benefits of music (Ilari, 2020).

Regarding the thorough review performed, it seems interesting to identify the guidelines that can be drawn from it and prove helpful for the design of experiences with social robots in music. In this sense, a positive assessment is given to the "social" value of the robot type proposed for music teaching so as to ensure success in these experiences. Similarly, this social value of the robot is highlighted in previous educational research (Azuar et al., 2019; Efstratiou et al., 2021; Rofi'ah et al., 2021). We concur with Ujike et al. (2019) on the prominent motivational value of the Pepper robot.

Similarly, it seems advisable to undertake experiences focused on the whole educational community with the aim of acquiring knowledge and experimenting from a specific school project, assigning robots the status of members of that same community, as reported by Arocena et al. (2022), Lau et al. (2020), López-Belmonte et al. (2021), and Van den Heuvel et al. (2022). Benefits can also be obtained from collaborating with parents and other people actively involved in students' life (Gasteiger et al., 2021). As for the evaluation of experiences, it would be interesting to monitor them on a long-term basis to check if the improvements in music teaching are permanent. As Woo et al. (2021) highlight, this temporal dimension is needed. In any case, an initiative of this kind requires the involvement and training of teachers, as well as the acceptance of the robots to be used, so that learners can improve their musical skills and capabilities.

Finally, we would like to highlight that the studies under examination provided evidence of positive effects on students' learning in the educational context related to music. This is also noted in previous studies (Cádiz et al., 2021; Chakraborty et al., 2021; Savery et al., 2021). Nonetheless, these results must be interpreted very cautiously, due to the limitations to generalize them because the sample used is so small. On the contrary, this low number of research studies equally makes clear the need for more studies involving the implementation of experiences associated with music and social robots and the assessment of their effectiveness, as addressed by Arocena et al. (2022). This could serve to replicate research initiatives and acquire a more complete understanding of how teaching–learning processes should develop to ensure high quality. Be that as it may, all four articles analyzed definitely exemplify good practices around the use of social robots in the music classroom.

In our case, and despite the current difficulty to evaluate robots' ability to directly influence learning results in music, it can be interesting to delve deeper into these possibilities already. Social robotics in education appears as a viable resource in the future. In this sense, we agree with several previous studies (Tanaka et al., 2015; Azuar et al., 2019) that point to this. Hence, the potential usefulness of this study is in breaking new ground.

4.1. Limitations and proposals for future

This study faced certain limitations, which are specified in the following paragraphs. The first one related to the small sample size and the consequent effect on the generalization of results. Although plenty of time was dedicated to trying and finding a larger sample of articles about this topic (based on the previously established inclusion criteria), the shortage of publications devoted to this field was verified. We could have modified the criteria or the topic, but that would not have been in keeping with the objective set at first. In fact, it became necessary to clarify some aspects because, when the research study was in full swing, we realized that certain aspects—e.g., academic performance—had initially not been addressed in a proper manner.

Another limitation worth highlighting had to do with the databases used. Although those sources are seen as two of the most important ones currently available to the scientific community, we did not resort to other possible sources. Moreover, we included references in English and Spanish; even though the former is the most widely used language in the scientific domain, references in other languages were excluded.

In addition to the aforementioned limitations, we are well aware that—as stressed in the PRISMA model—this type of research has an author-based bias since it is a "complex process that entails numerous assessments and decisions" (Urrútia and Bonfill, 2010: 508). As explained by these authors, "with the aim of minimizing the bias risk during the review process, such assessments and decisions should not be influenced by the results obtained in the articles included in the review" (Urrútia and Bonfill, 2010: 508). That is what we tried to do at all times, actually, but we may have introduced some bias in our study, perhaps because of our lack of experience in such research studies. It would be necessary to carry out a study in which different

evaluators could take part and also apply agreement measures (Morris et al., 2021).

Along these same lines, we would like to clarify that no biases have been introduced in the protocol. The latter was established *a priori* and, although we did not publish it, as suggested in the Cochrane model (Urrútia and Bonfill, 2010), it was transparent and did not change *a posteriori* because we knew that those changes would affect the results in some way or other. Urrútia and Bonfill (2010) insisted on the fact that "such decisions are very likely to introduce biases and must be avoided" (p. 508). That is what we did, explaining the changes made and their justification in the methodology section. In particular, before undertaking this research study, we made sure that there were no other reviews on this same topic so that duplications could be prevented. In this regard, we were unable to carry out an optimal "assessment of the bias risk at the level of studies or results" (Urrútia and Bonfill, 2010: 508), insofar as these studies were not performed following the same methodological approach, which makes it very difficult to compare both the studies themselves and their findings. After all, we have case studies as well as the application of certain standardized tests.

Added to the aforementioned points, some biases do exist in relation to the publications that shape the sample. We did not systematize the evaluation of methodological quality referred to the results which were relevant for each one of the selected studies by means of published rating scales (Morris et al., 2021). Apart from the lack of knowledge required to do this with sufficient certainty that the procedure was implemented correctly, the existence of methodological heterogeneity in the interventions largely hindered the evaluation of that methodological quality.

Despite its limitations, this study has implications that deserve to be considered when it comes to the use of social robotics in music teaching. That is why a future research line could contemplate directly utilizing a social robot in a classroom with different educational levels, from infant education to university teaching. It would be a way to supply additional perspectives and reflections about the experiences developed. Another potential path for research consists in giving voice to those students who experiment with social robots so that they could express their feelings and perceptions, among other things.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author/s.

Author contributions

RM, MC, and JE contributed to the conception and design of the study. RM conducted the literature search and wrote the first draft of the manuscript. MC and JE wrote sections of the Introduction and supervised the whole process. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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Task design for online learning: the case of middle school mathematics and science teachers

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Introduction: Teachers' task design in the context of online learning has been little researched by educational researchers. The current research examines the task design of science or mathematics teachers in the context of distance education based on the didactical situation theory and, in particular, situation types.

Methods: Fourteen teachers participated in the current study. They were interviewed regarding the situation types that they used to design online tasks. We used both deductive and inductive methods to analyze the transcribed interviews.

Results: The research findings showed that the teachers utilized different categories of the situation types. Moreover, the teachers utilized three types of reference as follows: the institution, the individual, and the tool. The participating mathematics and science teachers attempted to integrate argumentation into their designed tasks. Furthermore, the situation of communication was designed by the participating teachers to enable the interaction between and inside different agents of online education (students, teachers, and parents) while utilizing different communicational channels (mobile social networks, Zoom rooms, Zoom sessions, student's homes, and Google Classroom). The teachers designed situations of action to address the various aspects of learning, namely, the cognitive, social, affective, and psychological aspects.

Discussion: We argue that the design of online tasks could utilize the didactical situation of action, where the online students are requested to reflect critically on the online tasks. We recommend that teachers request reflection and feedback from their students regarding the tasks that they design for online learning.

KEYWORDS

didactical situation, situation type, task design, task types, mathematics teachers, science teachers, curriculum, activities

1. Introduction

Emergency education due to COVID-19 has impacted educational research that sought to study different aspects of emergency education (Cubilla-Bonnetier et al., 2023), especially distance learning during the emergency period (Garrote et al., 2021; Masalimova et al., 2022). As distance learning was not generally used in third-world education, emergency education accounted for professional development for teachers in the field of task design.

The phenomenon of task design in emergency education necessitates educational research into the utilization of this task design during the COVID-19 pandemic. The current research aimed to examine the task design by science or mathematics teachers by utilizing the situation-type framework as part of the didactical situation theory.

These types include the reference situation, the communication situation, the argumentation situation, and the action situation. Our attempt continues previous research to study task design in mathematics and science education, as well as previous attempts by researchers to study task design in technological environments. In addition, this research considers task design in emergency education as an opportunity for professional development for teachers in using online tools in task design.

In addition, task design is essential to teaching in all online learning environments, as well as in regular classes. Emergency learning can be considered an encouraging factor for distance learning, and technology practices during this period can guide our practices in online learning at regular times. Thus, the present research can direct teachers' practices of task design in regular online learning, which points to the utility of the practices that we report in the present research.

2. Literature review and theoretical background

2.1. Task design in education

Task design refers to the process of creating or structuring a task or activity that learners will engage in as part of their learning experience (National Research Council, 2002). It involves determining the objectives of the task, selecting appropriate materials and resources, and designing the structure and format of the task to maximize its effectiveness.

Design in education has been attracting the researchers' attention because of its influence on the learning science, including mathematics, and on aiding the students in their efforts to become scientists. The benefits of task design can vary depending on the focus of this design. For example, task design could be targeted at increasing the efficiency of teaching and learning, improving communication among the learners and between the teacher and learners, increasing productivity when the tasks are designed with a clear structure and direction, and enhancing creativity when the tasks are designed to motivate one or more types of creativity.

Researchers studied the influence of task design in educational contexts. Meslec et al. (2020) stated that the content and type of cognitive handling in a task will result in a variety of team creativity. Malicka et al. (2019) examined the influence of task design on students' language proficiency in the classroom. According to her research, highly proficient speakers took advantage of accuracy in terms of cognitive complexity, while modestly proficient speakers took advantage of structural complexity. In the current study, we examined task design utilizing the perspective of the didactical situation framework, specifically the situation type aspect of it.

In electronic mathematics learning environments, Cevikbas and Kaiser (2021) claimed that task design is an increasingly important area for mathematics education research. Daher et al. (2018a,b) described tasks as mediating tools in the context of mathematics education. Fahlgren et al. (2022) reported that preservice teachers could design not only technology-based tasks based on specific criteria but also design tasks without being aware beforehand of the tasks' criteria. Bozkurt and Koyunkaya (2020) reported that preservice teachers when observing each other's micro-teaching lessons and discussing this micro-teaching could devise and develop their designs of technology-based tasks.

2.2. Distance learning due to emergency education

Distance learning has attracted the attention of researchers since its beginning. This attention has increased during the emergency education that resulted from the outburst of COVID-19 (Hamdan et al., 2021). Different issues of distance learning due to emergency education were addressed by educational researchers. Abukhalil et al. (2021) investigated the criteria used by principals to assess the effectiveness of schoolteachers' tool use to support distance learning activities during the COVID-19 pandemic. The study results showed that the criteria that guided the principals in their assessments were associated with different aspects of teaching and learning. The study reported the following criteria that were mostly utilized in principals' assessments: the technological tools' accessibility to students, the ability of the teacher to handle them, the fit between the tool and the particular content, and their use for interactive communication in the classroom. Hamdan et al. (2021) targeted the assessment implemented by the universities through their e-learning departments during emergency education. They found that the universities went through two phases. In the beginning, they attempted to save as much as they were able to. Afterward, the assessment methods developed into ones that were dissimilar to those used before the emergency education. Alternative educational assessment methods were pursued. In the present research, we addressed a unique issue related to distance learning due to emergency education, which is task design during emergency distance learning.

2.3. Task design in technological environments

Researchers are concerned with task design and its impact on other variables across different fields and disciplines. This is especially true for technological educational environments. Mackrell et al. (2013) found that, through the use of software affordances and task design theories, instructors can efficiently create and implement teaching and learning resources. In addition, they argued that task design in the Cabri environment encourages awareness of various didactical variables. Håkansson Lindqvist (2020) concluded that technology must be included in the design process since it affects the division of responsibilities. Moreover, Håkansson Lindqvist (2020) suggested analyzing task design with technology using the following four criteria: (1) means and ends; (2) environment; (3) learning, cognition, and articulation; and (4) development.

Researchers were interested in the actual task design in technological environments. Sidawi (2009) found that teachers attempting to design activities with technology encountered many challenges, such as (1) their limited understanding of the compound relationship between technology and science, (2) their inability to transfer their science knowledge to technology design,

and (3) their inability to deeply understand the design process. The previous challenges made teachers' instruction linear without taking into account the problem context. In addition, Daher et al. (2022b) investigated mathematics preservice teachers' task design of programming activities utilizing Scratch. They found that preservice teachers were concerned with different paradoxes in the situation in their design. They were also concerned with both creative and algorithmic reasoning. In addition, the preservice teachers were not only concerned with students' devolution but also with following institutionalization. The preservice teachers' task design also included students' autonomy regarding the problem solution. The present research focuses on inservice teachers' task design during emergency education. To investigate this design, we used the didactical situation theoretical framework.

2.4. Theoretical background

The present study analyzed online tasks designed by mathematics and science teachers according to a didactical situation framework. Brousseau and Warfield (2020) described the didactical situation as organized to cause students to make a mathematical concept of their own. They stressed that organizers and students can be individuals, populations, institutions, and the like. In addition, adidactical situations are also described by Brousseau as instances of learning in which the teachers hide their involvement in the learning process and the students function without the involvement of the teacher (Brousseau, 2006). Brousseau (2006, p. 65–72) described three types of situations: the situation of action, the situation of communication, and the situation of validation. Brousseau (2006, p. 65–66) suggested that the action situation is related to what is effective, specifically the devolution and construction of knowledge processes in the classroom. Moreover, Brousseau (2006, p. 68–69) suggested that the communication situation is related to the social organization, such as to provoke the transmission of knowledge as well as the quality of social communication. Brousseau (2006, p. 68–69) suggested that the situation of validation includes the exchange of assertions and proofs between the participants in the didactical situation to arrive at an agreement regarding knowledge, where the agreement between the participants does not include "illegitimate" means, such as authority and force. Moreover, Brousseau and Warfield (2020) described four types of situations, and the fourth is the situation of reference. The situation of reference occurs when one educational agent refers to another to exchange information, tool, resource, and so on.

Table 1 illustrates the previous descriptions of the situation types.

2.5. Research rationale and goals

Laurillard et al. (2018) argued that research should address a design that supports technology use in education. Emergency education, especially the need for online learning and the use of digital tools, highlighted the need for research on technology-based task design. In this study, we investigated mathematics and science teachers' designs of online activities during COVID-19, utilizing the didactical situation theory, specifically the situation types that are part of the theory.

Researchers were interested in task design in technological environments. For example, Gustafsson (2016) developed design principles and task types for tasks that follow a multiple-choice format in the context of classroom response systems. Albay and Eisma (2021) argued that using design thinking processes can support teachers in maintaining a classroom that is creative, interactive, and engaging. The present research aimed to address an issue related to design in emergency education and related to online learning. Specifically, we attempted to understand mathematics and science teachers' designs of online tasks using the perspective of the situation types. A few studies have utilized the didactical situations framework. This is especially true regarding the use of situation types to study teachers' designs of tasks as part of distance education.

Previous research that utilized the theory of didactical situations to study task design focused on the devolution and institutionalization processes without paying special attention to the situation types (Daher et al., 2022a). In addition, only a few studies have investigated task design using technological tools for students' learning, especially tools that fit distance learning. The current research intends to contribute to this issue.

2.6. Research questions

First question: What types of didactical situations do mathematics and science teachers use in emergency distance education?

Second question: What categories of each didactical situation type do mathematics and science teachers use in emergency distance education?

3. Methodology

3.1. Research context and participants

In this study, we addressed the design of distance tasks by middle school science and mathematics teachers. A total of 14 teachers participated in the current study, who were equally distributed between mathematics and science teachers. Table 2 describes these teachers in terms of discipline and years of experience.

3.2. Data collection tools

Mathematics and science teachers were interviewed about their design of science and mathematics tasks for online learning during COVID-19. The semi-structured interview began with questions such as, "Can you describe activities that you implemented in the frame of online learning during emergency education?" The interview moved on to the most important questions, which addressed the different types of didactical situation and their characteristics. In doing so, we asked opening questions such as,

TABLE 1 Types of situations.

Situation of action	Situation of communication	Situation of validation	Situation of reference occurs
1. Devolution 2. Construction of knowledge processes	1. Provoking the transmission of knowledge 2. Provoking the quality of social communication	1. Exchange of assertions between the participants 2. Exchange of proofs between the participants	Reference of one educational agent to another to exchange 1. Information 2. Tool 3. Resource

TABLE 2 The participants in terms of discipline and years of experience.

Teacher's fictive name	Discipline	Years of experience
Salam	A mathematics teacher	13
Kamal	A mathematics teacher	12
Amir	A mathematics teacher	8
Hamida	A mathematics teacher	12
Ruba	A mathematics teacher	14
Sami	A mathematics teacher	15
Kamal	A mathematics teacher	9
Soad	A science teacher	20
Heyam	A science teacher	12
Maram	A science teacher	14
Mosab	A science teacher	16
Bayan	A science teacher	15
Adan	A science teacher	7
Samira	A science teacher	12

Can you describe activities that take care of situations of reference? Describe activities that take care of the situation of argumentation. Specific questions were also asked, such as, Do you think that it is easy to design activities that take care of situations of reference? What are the problems of designing activities that take care of situations of argumentation?

3.3. Data analysis tools

To determine how participating teachers designed online tasks for emergency education during emergencies, the analysis used both deductive and inductive reasoning. Deductive reasoning utilized the categories related to the situation type (see Table 2 for more detail).

A previous study by the same authors utilized the didactical situation framework to analyze science and mathematics teachers' task designs (Daher et al., 2022a). In that study, we utilized constructs that were different from the current one, but they were also related to the didactical situation. In that study, the main studied constructs were the processes of the situation (e.g., devolution, creative processes, and autonomy), while in the present research, the main constructs are the types of situation (e.g., reference situation, information situation, and argumentation situation). The two studies addressed different aspects of the task situation, and on collectively considering the different aspects, the authors helped us to understand science and mathematics teachers' task designs for online education.

3.4. Validity and reliability

The trustworthiness criterion was used to evaluate the analysis method (Lincoln and Guba, 1985). Trustworthiness addresses the argument that the results are worth paying attention to (Elo et al., 2014). It was analyzed through different constructs, specifically, credibility, dependability, conformability, transferability, and authenticity. We described them according to the study of Elo et al. (2014).

3.4.1. Credibility and dependability

To justify credibility, we identified the research participants and accurately described them. This identification and accurate description also addressed dependability, which means that the data were stable in varied contexts. According to researchers, the stability of data could be obtained when the principles followed to choose participants were disclosed and clear (Elo et al., 2014), allowing us to assess and perform the transferability of the results to other contexts (Moretti et al., 2011). In our case, we interviewed math and science teachers for the ninth grade. The credibility and dependability of the research result from our description of the participants in terms of their background variables. Furthermore, they result from our attempt to take into account the homogeneity of the participants (Burmeister and Aitken, 2012).

3.4.2. Conformability

The conformability of data relates to how accurately the findings reflect information provided by the participants and how appropriate the interpretations are to the findings (Polit and Beck, 2004). We have addressed conformability in this study by calculating the agreement between coders. As part of the didactical situation, four coders searched for occurrences of phrases, indicating a situation type. Cohen's Kappa coefficient, representing the agreement between the coders, indicates that the qualitative coding is reliable and, upon computation, it resulted in the values of 0.89–0.93 for the four situation types associated with task design. For achieving agreement between coders, these values are acceptable.

TABLE 3 Categories and themes used in the deductive reasoning.

Situation type	Definition	Examples on themes
Reference situation	A situation that occurs when a participant in the situation refers to another participant	Refer to the ministry of education, refer to the book, refer to an internet site
Information situation	A situation that occurs when a participant is engaged in sharing information with other participants	Share information, interact, compare information
Action situation	A situation that occurs when a participant acts on an object in the situation	Act to change knowledge, act to motivate, act to cause positive emotion
Argumentation situation	A situation that occurs when a participant justifies a claim or an action	Justify a claim, justify an action, tries to persuade regarding a claim

3.4.3. Transferability

The concept of transferability is related to the notion that a study's findings may be extrapolated to other contexts or participants. Transferability is satisfied when giving a clear description of the context and the selection of participants. It was addressed by describing in detail the research context, including participants. It increases through a detailed analysis of the data. Table 3 shows the definition of situation types taken care of in the present research.

We started the research by looking for codes related to each situation type. For example, codes related to the reference situation include "talked to," "addressed ….," and "interacted with …." We searched then for codes related to the subject of reference. The subject could be "the teacher," "another student," "the book," and "the ministry of education." In the third phase, we attempted to relate a code from the first phase with a code from the second phase. In the fourth phase, we searched for the condition of the reference. For example, we arrived at this phase under the condition that "the design according to reference to the ministry of education occurred starting from the beginning of the emergency education."

3.4.4. Authenticity

Authenticity refers to how well researchers present a range of realities (Burmeister and Aitken, 2012; Albay and Eisma, 2021), and it is susceptible to the mistakes of inexperienced researchers who lack the necessary knowledge or skills. In this research, authenticity was examined and ensured by computing the agreement between judges. Furthermore, to ensure authenticity, we followed previous qualitative studies (e.g., Daher and Swidan, 2021; Salhab and Daher, 2023), which strengthened the authenticity of the research methods.

3.4.5. Saturation in the research

Saturation was arrived at when analyzing the 11th interview, where no new situation type was arrived at. In addition, after the 11th interview, the properties of the situation types emerged as in the previous 11 interviews. Despite the repetition of occurrences of the situation types, we analyzed the rest of the interviews, which also showed the repetition of the situation types and their properties.

3.5. Ethics statement

The present research addressed teachers' designs of online activities and relied on interviewing the participants about educational practices. A written informed consent form was signed by the participants. This form included a statement about the interview in the research being voluntary, the ability of the participant to withdraw at any phase during the research, the ability of the participant to refuse to answer any interview question, the agreement to record the interview, the anonymity of the participant, a summary of the purpose and procedure of the research, and the expected benefits of the research.

4. Results

The following sections describe the different situations addressed by the participating teachers when designing online activities as the main channel of learning in emergency education.

4.1. Situation of reference

The categories of the situation of reference were the following: reference to the ministry of education, reference to the teacher, reference to the student, reference to the book, and reference to an Internet site.

4.1.1. Reference to the ministry of education

According to reference to the ministry of education, the design started with the beginning of emergency education. Emergency education made the ministry of education intervene and suggest online tasks for the different disciplines and grades. Salam, a mathematics teacher, described the efforts performed by the ministry of education to provide appropriate materials for online learning at the beginning of emergency education. She said, "When we first started, the ministry of education offered support. It provided us with learning materials appropriate for online teaching. This hugely helped us because we were not accustomed to this type of teaching."

4.1.2. Reference to the teacher

According to reference to the teacher, the design also started with the beginning of emergency education and continued along with this education. Kamal, a mathematics teacher, described his attempts to fit the textbook into online education: "We needed to adjust the textbook into tasks that suit the online learning. To do so, we searched, found, and used technological tools valid for designing online communication and for students' investigations of the subject matter."

4.1.3. Reference to the student

According to reference to the student, the participating teachers indicated the design began in two situations. The first case occurred when the student was requested to present a topic in the subject matter to the whole class, resulting in the student becoming a reference. Soad, a science teacher, said, "I wanted the students to be active in online learning, so I requested some of them to present topics from the subject matter. For example, one student presented material about energy." The second case occurred when the students were requested to investigate by using technological tools, relations, and concepts in the subject matter. Ahlam, a mathematics teacher, said,

I wanted the students to rely on themselves in discovering the mathematical relations and concepts, so I designed tasks in which they used GeoGebra to discover the relations and concepts. During a task, the students studied the meanings of the parameters "a" and "b" in the linear function.

4.1.4. Reference to the tool

The teachers designed a didactical situation that referred to the technological tool when the emergency situation did not allow for using the regular tools. Heyam, a science teacher, emphasized the importance of technological tools that replace the traditional laboratory in which the student conducts practical experiments. She said,

> In COVID-19 pandemic, it was difficult to attend the science laboratories. I designed tasks in which the student experiments through the Crocodile program. The student sees the colors of the resulting materials and can measure the heat of the reaction. The students expressed their enthusiasm of the experimentation, saying that they enjoyed working with the program and that it made them understand the content.

4.1.5. Reference to the book

Reference to the book was designed as a stand-alone task only at the beginning of the emergency education. Amir, a mathematics teacher, described his use of the regular book at the beginning of emergency education: "At the beginning, I referred the students to their own book and asked them to write their answers in the WhatsApp group." As the teachers became accustomed to online learning, they referred the students to the regular book at the end of the lesson to provide them with a resource that could help them to prepare for the exam. Maram, a science teacher, describes her use of the book as a learning resource:

> I wanted the students to have more than one resource that helps them in the preparation to the exam. When a lesson came to an end, I told the students where, in the book, they can find the material that I taught them. I told them they can use it whenever they want, especially to prepare for the exam.

4.1.6. Reference to an Internet site

When designing online tasks, the participating teachers considered the Internet site as a vital reference for students to use to study the learning material. The reference to an Internet site happened generally in three situations. The first occurred when the teacher built the Internet site. Mosab, a science teacher, described his building of Google docs and forms at the beginning of the emergency:

> Internet sites helped us a lot in designing the online tasks. I used them for different tasks. For example, I used Google docs and Google forms at the beginning, because we had a workshop on the use of these tools at the beginning of the emergency. I used them not only at the beginning, but these were the first internet sites that I used.

The second situation occurred when the teacher referred the students to already-built sites. Hamida, a mathematics teacher, described sites that she referred the students to practice the new knowledge they had acquired: "I designed tasks in which the students played an online game to practice their knowledge." The third situation occurred when the teacher referred the students to a site that she or he built, but the students participated in continuing the building of this site. Bayan, a science teacher, described the online tasks she designed where students built an Internet site collaboratively:

> The Padlet helped me when I wanted to raise an issue and I wanted my students to write their ideas regarding this issue. For example, I did that to solicit students' perceptions of the topic of "growth, development, and reproduction of organisms."

4.2. Situation of argumentation

The following texts describe the categories of the situation of argumentation.

4.2.1. Argumentation during the teacher's introduction of the topic

Ruba, a mathematics teacher, described her design of a didactical situation in which she asked the students to provide an explanation based on their observations. She said: "They were asked why veins have thin walls, for example, while arteries have thick walls."

4.2.2. Argumentation during students' investigation of the topic ideas

Ruba, a mathematics teacher, described her design of tasks in which the students were requested to justify their observations after they worked with a technological program. She said:

> In the tasks that I design with a technological program like GeoGebra, I ask the students to justify their observations after they worked with the technological program. For example, they tell me that the "m" parameter affects the angle that the linear function makes with the positive direction of the x-axis. I request them to justify this influence.

4.2.3. Argumentation investigated through technological programs

Adan, a science teacher, described her design of tasks in which the students are requested to justify their arguments by working with technological programs.

> I designed different educational situations in which the students were requested to justify their observations. One such situation is that related to the factors affecting the kinetic energy of a body, where a discussion took place among the students, some of them said that kinetic energy increases with increasing mass, while others mentioned that kinetic energy increases with increasing speed. It was a fruitful discussion that was followed with justification by implementing an experiment to calculate kinetic energy using the simulation program "PhET."

4.3. Situation of communication

4.3.1. Students' use of mobile social networks to communicate

Samira, a science teacher, built a WhatsApp group to motivate her students' communication during distance learning. She said,

> Each class had a WhatsApp group that I built. It was used to discuss all aspects of mathematics by the students. I also used WhatsApp to put difficult questions. These questions were designed with the assumption that students would ask about its contents, or methods of solving it.

4.3.2. Communication between the students with Zoom rooms

Salam, a mathematics teacher, used Zoom rooms to provide her students with a collective environment for the discussion of new topics. She said, "At the start of new topics, I used Zoom rooms for students to communicate and that helped them understand. This happened when the students learned negative numbers."

4.3.3. Eyes communication between the teacher and students in Zoom sessions

Sami, a mathematics teacher, stressed the relationship between communicational actions and social interaction, where interaction by the eye is crucial to students' learning. He said,

> Listening is not sufficient for the student. Just listening makes the student get lost. Students need to be engaged in the lesson and the camera needs to be on. When the student gives an explanation, it would benefit her to elaborate on specific points during the explanation. As a teacher, you provide the initial content and lead the discussion among the students in the tasks that I design. We used different applications to encourage student interaction: the interactive whiteboard, live worksheets, and FullProof.

4.3.4. Communication between parents and children at home

Samira, a science teacher, described her design of science tasks that parents and students collaborate to carry out at home: "I designed some tasks to be carried out at home, with the supervision of their parents. For example, the students carried out the solar oven task, with the supervision of their parents. This task is considered a safe one."

4.3.5. Communication among teachers, students, and parents on Zoom

Soad, a science teacher, described her design of science tasks to be presented in the parent's presence on Zoom: "I designed tasks to presented in the presence of parents in Zoom. One such task consisted of a virtual gallery that the students built with Genially."

4.3.6. Communication between teachers on the online platform

Salam, a mathematics teacher, detailed her interaction with fellow teachers in the environment of Google Classroom: "There is a group dedicated to mathematics teachers in the district. All the teachers put the online tasks that they design in the group, and the teachers use each other's task."

4.4. Situation of action

4.4.1. Action to provide students with learning materials

The first situation of action that the mathematics and science teachers wanted to design is one in which the students have learning materials so that they can continue studying. Kamal, a mathematics teacher, described his attempts to design tasks so that his students have their learning materials:

> As COVID-19 started, I focused on designing learning materials to be used by my students for all their coursework. In the beginning, this was through using the WhatsApp application to put the number of pages in the book. I requested

> the students to take photos of their solutions and put them in the WhatsApp group. I corrected the solutions and sent the corrections to the students individually. It was a time of emergency. All that I wanted was to proceed with the educational process. The first goal was to provide the students with learning material.

4.4.2. Action to make students enjoy online learning

Bayan, a science teacher, described her design of tasks in the chemistry classroom to make her students enjoy their online learning:

> I built a task in which I took advantage of the table of elements. The students find their symbols difficult as they are in Latin. The task required the students to build meaningful sentences from the elements symbols. They built sentences such as "Happy Eid Al-Fitr," or "Be aware in emergency." The last sentence fitted the emergency period. The students loved to participate in this task so much.

4.4.3. Action for motivating students' participation in online learning

Hamida, a mathematics teacher, described her design of a mathematics task to motivate her students' participation in online learning: "I designed tasks that included games to motivate my students to participate in online learning. One such task involved factors of numbers. I used the NCTM game applet 'Factor Game'."

4.4.4. Action to make students work collectively to solve difficult problems

The mathematics and science teachers designed online tasks to make students work collectively when they expected that the solution process of the problem would be facilitated by collective work. Ruba, a mathematics teacher, described her engagement with such a design: "When I expected the problem to be solved more easily when the students worked collectively, I designed it to be solved in Zoom's rooms. I joined each group of students to direct the process of the solution if needed."

5. Discussion

The study was conducted to examine the design of tasks implemented by science and mathematics teachers during emergency education, based on the situation-type framework. In the following section, we discuss the research findings by referring to each situation type.

5.1. Situation of reference

The participating mathematics and science teachers used different reference situations to design online tasks for their students. These references included the ministry of education, the teacher, the student, the tool, the book, and the Internet site. It has been suggested that the previous references are of four types. The first type is the institution, with the ministry of education serving as an example. The reference to the ministry of education has been reported by researchers as supporting online learning during the COVID-19 pandemic. For example, Abukhalil et al. (2021) reported that the Palestinian Ministry of Education initiated strategies and techniques appropriate for distance learning to manage the state caused by the COVID-19 pandemic.

The second type of reference is the individual, here the teacher or the student. The teacher is the one who designed it. As a result, the teacher was actively involved in finding appropriate resources and tools for designing the online tasks, and she or he became the main reference for the didactical situation. The teacher, as a reference, does not here imply her or his role in the implementation of the lesson, but her or his main role in designing the online lessons. When the student was a reference, she or he had autonomy in investigating the mathematical or scientific relations in the subject matter. This characteristic of the student as reference points to the potential of online learning enable students' voices in an educational context, a characteristic that is enabled in technology environments (Daher, 2017).

The third type of reference is the tool. The participating teachers reported that they benefited from tools in their design in providing a means for students to experiment in order to arrive at mathematics and scientific ideas and relations. It means that the participating teachers were able to continue or start taking advantage of tools for investigative work by students in their task design (Daher, 2009). The fourth type of reference is the text and whether this text is from a regular book or an Internet site was investigated. The text here functions as a formal resource that students could refer to in order to verify their self-formulation of mathematical and scientific relations. In this situation of reference, the role of the teacher was to indicate the text rather than mediate the text. This role of the teacher is expected because the tools facilitated students' learning before they referred to the text.

5.2. Situation of argumentation

The situation of argumentation included three types of argumentation: argumentation during the teacher's introduction of the topic, argumentation during students' investigation of mathematical or scientific ideas, and argumentation investigated through technological programs. Wells (2014) argued that it is possible to focus students on the importance of quality evidence if argumentation structures and practices are introduced, and this could lead them to become more interested in math content. In the present research, we found that an attempt was made by the participating mathematics and science teachers to integrate argumentation into their designed tasks.

5.3. Situation of communication

The situation of communication was designed by the participating teachers to enable interaction between and inside different agents of online education (students, teachers, and

parents) while utilizing different communicational channels (mobile social networks, Zoom rooms, Zoom sessions, students' homes, and Google Classroom). The different interactions and channels point to the rich potentialities of communication that distance education provides for educators and students.

5.4. Situation of action

The teachers designed situations of action to address the various aspects of learning, namely, the cognitive, social, affective, and psychological aspects. Although it was a time of emergency, the teachers were concerned with the different aspects, probably because the different aspects were considered crucial for students' learning (Daher, 2011; Daher et al., 2018a; Daher and Awawdeh Shahbari, 2020).

An investigation of task design for mathematics and science teachers during online learning was conducted by Daher et al. (2022a). Using the technological tools, the participating teachers were able to design tasks that allow students to take charge of their own learning activities. A successful didactical situation was achieved by utilizing the potential of distance learning platforms.

6. Conclusion and recommendations

Emergency education arose suddenly due to COVID-19 and impacted many aspects of education, especially distance education (Naji et al., 2020). The present research sought to study the influence of online education on teachers' task design. The research results indicated that the teachers considered argumentation as part of their design. More research is needed to verify the role of argumentation in online learning of mathematics and science, especially in times of emergency.

In the frame of their concern with the didactical situation of action, the research participants were concerned with the different aspects of the student's online learning. Future studies have been requested to investigate how this concern developed, for example, which aspect the teachers were concerned with at the beginning and which one came last.

Mackrell et al. (2013) recommended that the design of tasks that include software could benefit from classroom feedback, where this feedback suggests ways in which the task may be improved. We argue that the design of online tasks could also benefit from a didactical situation of action, where students who participate in the online classroom are requested to reflect on the online tasks. We recommend that teachers request feedback from their students regarding the tasks that they design for online learning.

Yeung et al. (2012) argued that to effectively use digital technologies in the classroom, teachers must develop their digital competence. To increase teachers' confidence in applying teaching technologies, the authors suggested increasing their digital technology competence. Thus, we recommend that teachers participate in workshops in which they discuss and implement the design of online tasks so that they become experienced in this aspect of online teaching. This would prepare them for the design of online tasks when the educational conditions demanded this design.

Radloff et al. (2019) found that preservice teachers engaged with and applied standards-based science content when they developed and implemented compost design tasks. Here, mathematics and science teachers were able to apply online teaching during emergency education through the development and implementation of task design.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

SS, RJ, ID, AA, KS, MB, and MR collected the data and performed the statistical analysis. WD wrote the first draft of the manuscript. All authors contributed to the conception, design of the study, manuscript revision, and read and approved the submitted version.

Conflict of interest

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

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Lëttëra web platform: A game-based learning approach with the use of technology for reading competence

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Introduction: This study explores the potential of technology, metacognition, and game-based learning to improve reading literacy in upper secondary school students. The focus is on the Lëttëra educational innovation, a web-based platform that uses game-based learning and technology to develop reading literacy.

Methods: This is a quantitative, exploratory, descriptive, and quasi-experimental study that reviewed 149 responses from high school students who took the standardized test Planea 2017. The study aimed to analyze whether using the Lëttëra platform brought a change in the students' reading competence. The authors also examined students' motivation toward technology, the platform interface, and the game. The data was analyzed both descriptively and inferentially.

Results: The results showed that using the Lëttëra platform significantly improved students' competencies in literary text, information construction, and argumentative text. It also increased their motivation toward the proposed activities.

Discussion: This study demonstrates that integrating technology and game-based learning into reading instruction can lead to improved reading competencies and increased motivation among students. These findings are useful for educators, curriculum developers, and policymakers who aim to enhance reading instruction by integrating technology into their teaching practices.

Conclusion: Overall, this study highlights the potential of technology and game-based learning to improve reading literacy in upper secondary school students. The Lëttëra platform provides a promising approach for enhancing reading instruction, and its integration into teaching practices can benefit students, educators, and policymakers alike.

KEYWORDS

reading competence, game-based learning, metacognition, educational innovation, learning for life, professional education, higher education

1. Introduction

Nowadays, we live in a society where human beings are bombarded daily with visual and auditory information through various forms of media. This is precisely why reading competence for young people is vital, as they are confronted with multiple textual or graphic issues in which

their reading level is the basis for their decision-making. Furthermore, reading is a fundamental skill for success in adult life (OECD, 2013). However, it is observed that acquiring these skills is challenging for young. This situation generates disinterest and frustration in them, added to the fact that the media used is not attractive for their age and that their interests have been changing due to the availability of new technologies.

The emergence of e-books, audiobooks and other digital reading platforms has brought about a considerable change in the way individuals read. Technology has advanced our reading habits and sparked interest in both young people and adults (U.S. Department of Education, National Center for Education Statistics, 2018). Sun et al. (2021) indicate that interactive experiences, such as online book clubs and digital storytelling apps, can increase curiosity toward reading for all ages. Additionally, during a pandemic like COVID-19 where social distancing impacts education, teachers are using educational projects that incorporate technology to develop students' reading skills while bringing them closer together (Grynyuk et al., 2022).

According to the most recent results of the Organization for Economic Cooperation and Development (OECD) Programme for International Student Assessment (PISA), applied in 2018 because due to the Covid-19 Pandemic (the 2021 one was postponed to 2022), Mexican students scored below the international average. According to Salinas et al. (2018), "in Mexico, only 1% of students performed at the highest proficiency levels (level 5 or 6) in at least one area (OECD average: 16%) and 35% of students did not obtain a minimum level of proficiency (Level 2) in all 3 areas (OECD aver-age: 13%)" (p. 3). Although several efforts have been made at the national level to increase reading literacy among students aged 15 and older, average performance has remained stable in reading, mathematics, and science throughout most of Mexico's participation in PISA (Salinas et al., 2018). Since 2000, when Mexico first participated in this test, there has been no progress in any of the assessed areas.

Assessment is one of the essential features to ensure the quality of education systems in developed countries. Although efforts have been made in Mexico to assessment for primary and secondary education in the last two decades through three standardized tests: EXCALE, Planea and PISA (Caracas Sánchez and Ornelas Hernández, 2019) and the National Institute for the Evaluation of Education (INEE) by publishing studies and literature on the subject to reinforce practical exercises that have an impact on increasing reading comprehension, the student's results have remained the same. Another important aspect is support for teachers on motivation, knowledge, and tools to make them aware of their transformative power and the need to use ICTs to achieve learning (UNESCO, 2017).

For this reason, encouraging reading competence and developing educational innovation based on games and technology to help improve this skill in high school students. In this sense, the development of reading literacy in the high school period is transcendental for them to become actively involved in society, considering that having deficiencies in reading skills can limit their potential for the future (Sucena et al., 2022). Reading literacy is defined as understanding, evaluating, reflecting on, and engaging with texts to achieve one's goals, develop knowledge and personal potential and participate in society (OECD, 2018). However, the scientific literature related to the use of ICT in reading processes is still scarce (Fernández Batanero et al., 2021), even though the use of digital tools and active pedagogical strategies favor the development of these competencies (Neira-Piñeiro, 2015; Badillo-Jiménez and Iguarán-Jiménez, 2020).

This study seeks to analyze how technology used in an entertaining way (game-based learning) helps to visualize metacognition and makes the development of critical thinking necessary to foster reading competence in a user-friendly and us-er-friendly way self-manageable. Therefore, the research objectives were: (1) Analyze how the use of technology in the form of games can improve the reading competence of high school students in Mexico; (2) Evaluate the impact of the use of the web platform Lëttëra on the reading competence of students, and (3) Identify how students perceive the use of technology in reading learning and whether this affects their motivation and satisfaction with the learning process. These objectives have has been addressed through a comparative study of the results obtained from applying the Planea 2017 test before and after using the web platform Lëttëra, a web platform designed according to PISA's proposed reading comprehension processes and performance levels. The variables measured were based on the result of academic performance with the Planea 2017 test and student satisfaction, assessed through a survey.

Although there are some studies that demonstrate the benefits of using digital tools and active pedagogical strategies to promote reading, there has not been enough research on how game-based learning can improve metacognition and critical thinking in secondary school students, which is considered fundamental for the development of reading competence. In addition, many studies conducted in Mexico have shown that students' results in standardized reading tests have been insufficient, indicating the need to implement new pedagogical strategies and tools to improve the quality of education and the development of reading competence. This study can be useful for educators, educational technology designers, researchers in the field of education, and decision-makers in educational policy who are interested in improving the reading competency of secondary school students in Mexico using technology, particularly online educational platforms. Additionally, the study's findings can be helpful for parents and students interested in using technology effectively to enhance reading learning.

2. Literature review

2.1. Programme for international student assessment test

The design of the reading comprehension exercises of the Lëttëra Web platform is based on the PISA test based on the rationale that the current assessments in Mexico are aligned with it. In addition, it represents a commitment by the governments of OECD countries to regularly monitor the performance of education systems in terms of student achievement within a common internationally agreed framework (OECD, 2018).

The PISA test aims to assess whether 15-year-old students have acquired the knowledge and skills to participate fully in a knowledge-based society. The test is developed and coordinated by the OECD and evaluates students' abilities in reading, mathematics, science, collaborative problem-solving, financial literacy, and global competence (U.S. Department of Education, National Center for Education Statistics, 2018). The tests are administered to a sample of

students from each participating country, and the results provide an opportunity for countries to compare their educational systems with those of Civini (2019). It is therefore an important tool for policymakers, educators, and researchers to evaluate the effectiveness of educational systems in different. It is administered every 3 years and focuses on three core areas: reading, mathematics, and science (Bohrnstedt and Stancavage, 2016).

The definition of reading has changed over time, mainly as the internet has generated new ways of reading and is now seen "as an expanding body of knowledge, skills and strategies that individuals construct over a lifetime in diverse contexts, through interaction with peers and the wider community" (OECD, 2018, p. 9). In this way, PISA organizes reading literacy into three dimensions: *text, situations,* and *processes*.

The way content is presented in texts determines how they are managed. This can either be continuous, where sentences and paragraphs form broader structures like articles, essays or stories; non-continuous, organized from non-sequential information such as diagrams, infographics or advertisements; or mixed when combining the two forms (OECD, 2017). To cater for target audience and purpose of creation, texts are categorized into personal, public educational and occupational situations. The interaction between readers and text determines cognitive processes which include locating information comprehension evaluation, and reflection on it (OECD, 2018).

From 2018 onwards, this assessment has included texts presented digitally. These texts are classified according to (1) how information is accessed (static or dynamic); (2) the amount of information displayed (single or multiple single sources with two or more sources); (3) their format (continuous, non-continuous, and mixed) and (4) their discursive purposes (narrative, expository, argumentative, prescriptive, and transactional).

The Lëttëra web platform uses continuous, discontinuous, and mixed texts. It is based on the cognitive processes 1c to 3 suggested by PISA (National Commission for the Continuous Improvement of Education, 2018). For the underlining and commenting part of the reading, through distinguishing between different colors, to metacognitively direct the reading competence, as well as in the design of the reading challenges or exercises, as well as providing users with immediate feedback, relating the performance levels to the PISA reading competence as shown in Table 1.

The most basic levels are the first five:1c, 1b, 1a, 2, and 3; the highest performance levels are 4, 5 and 6. This first edition of the Lëttëra Web Platform is designed to help users develop their skills on the first five levels.

2.2. Assessing reading literacy through standardized tests in Mexico

According to Caracas Sánchez and Ornelas Hernández (2019), in Mexico, evaluation played a relevant role in the 1980s. Evaluation

TABLE 1 Reading literacy performance levels, PISA 2018 (National Commission for the Continuous Improvement of Education, 2018, p. 44).

Performance level	Description of achievement
3	- Identify the literal meaning of single or multiple texts without explicit content or organizational clues. - Integrate content and generate basic and more advanced inferences. - Integrate several parts of a text to identify the main idea, understand a relationship or interpret the meaning of a word or phrase when the necessary information is presented on a single page. - Search for information based on indirect cues and locate target information that is not prominently displayed or is accompanied by distractors. - In some cases, recognize the relationship between various pieces of information based on multiple criteria. - Reflect on a text fragment or a small set of texts and compare and contrast the points of view of various authors based on explicit information.
2	- Identify the main idea in a text of moderate length. - Understanding relationships or interpreting meaning within a limited part of the text when the information is not relevant, and the reader must make basic inferences, or when the information is in the presence of some distracting information. - Selecting and accessing a page in a set based on explicit, but sometimes complex, indications and locating one or more pieces of information based on multiple, partially implicit criteria. - Reflect on the general purpose, or the purpose of specific details, in texts of moderate length when explicitly asked to do so. - Reflect on simple visual or typographic features. - Compare claims and assess their reasons based on short and explicit statements.
1a	- Understand the literal meaning of sentences or short passages. - Recognize the central theme or author's purpose in a text on a familiar topic and make a simple connection between several adjacent pieces of information or between the information given and their prior knowledge. - Select a relevant page from a small set based on simple prompts and place one or more independent pieces of information within short texts. - Reflect on the overall purpose and essential and accompanying information in simple texts containing explicit clues.
1b	- Evaluate the literal meaning of simple sentences. - Interpret the literal meaning of texts by making simple connections between adjacent pieces of information in the question or text. - Look for and locate a piece of information highlighted and explicitly placed in a single sentence, a short text, or a simple list. - Access a relevant page from a small set based on simple prompts when there are explicit signals.
1c	- Understand and state the meaning of short, syntactically simple sentences on a literal level. - Read with a clear and simple purpose in a limited time.

through standardized tests was a strategy used to improve the country's education system due to educators' high attrition rate and low efficiency. In that decade, Mexico created the National Evaluation Centre for Higher Education (CENEVAL) to regulate the evaluation of education in the country, as the International Monetary Fund and the World Bank assigned economic resources for teaching in Mexico as support to settle the country's foreign debt (Aranda Izguerra, 2005).

One of the conditions for allocating resources was the commitment to improve education. So, through the design and application of standardized tests such as Planea or PISA, the country would substantially improve the education system. Starting in 2000, the OECD, through PISA, began the application of international tests for 15-year-old students. Mexico requested that the PISA test be applied in educational institutions to improve education and fulfil its commitment. The PISA test focused on finding performance indicators in mathematics, science and reading. This assessment does not focus on the curricula of the participating countries but on the progress of young people coping with the knowledge society (Jiménez Moreno, 2016).

2.3. Self-directed learning

A self-directed learner is to identify and achieves goals through effective learning strategies to understand, monitor, direct, evaluate and reflect on their process, ultimately taking control that enables them to decide which methods to use. Students must be self-directed learners to experience effective education and lifelong learning (Bagheri et al., 2013).

The Lëttëra web platform promoted the students' self-directed use of the exercises. The platform had an immediate feedback system that allowed students to learn about the cognitive process required to answer each question and the justification that determined the correct answer for each item. Another factor that eased the self-directed use of the platform was the challenge map that visually placed the students' progress to achieve all the activities. The last factor was determining the time to complete the activities since, during the semester, the students had some weeks to complete all the reading exercises.

2.4. Game-based learning

The design of the Lëttëra web platform considered the components that provided an attractive learning environment for high school students. These components were: the use of technology, gamification, self-directed learning, and metacognition through the underlining of PISA cognitive processes in the texts. Gamification refers to the incorporation of game design elements such as point systems, leaderboards, and rewards into non-gaming contexts (Høiseth et al., 2021). The goal of gamification is to increase motivation, engagement and participation in activities that are not inherently fun or interesting by making them more enjoyable through game-like (Bicen et al., 2022) Lettera web is based mainly on the gamification methodology. Games have long been known in the educational world for their effectiveness in applying goals such as having fun, socializing, and learning, and consequences such as winning and losing according to a specific rule system (Baran et al., 2018). In recent years, gamification has gained more popularity among teachers due to the gamified designs and game mechanics added to a non-game process (Wong et al., 2022). This has been embraced across a range of fields including education, healthcare, marketing, and customer service.

In general terms, a game is an application, while gamification is a process where game components are integrated into a non-game environment (Attali and Arieli-Attali, 2015; Abdul Ghani et al., 2022). The main objective of gamification is to effectively implement the positive effects of gaming in educational environments to increase student engagement, stimulate their educational participation, and improve outcomes (Deterding et al., 2011). Gamification seeks to harness the power of games to solve real-world problems (Hüseyin et al., 2020), making it the most appropriate approach to use on the Lëttëra web.

Different studies have analyzed the use of gamification in the school environment. In the last 2 years, due to the COVID-19 pandemic, initiatives have emerged that seek to improve student motivation in virtual environments due to social distancing (Chans and Portuguez Castro, 2021). Singh et al. (2021) identified that online activities require greater self-regulation and motivation for students to participate, so technology plays a fundamental role in improving methodologies; they also suggest that creating gamified environments enhances interaction and collaborative learning.

Another study by Chans and Portuguez Castro (2021) was conducted in the Mexican context, where students could carry out gamification activities in chemistry classes. The results showed that gamification elements such as autonomy and feedback allowed for the development of intrinsic motivation of learners. In the case of language teaching, Alharbi and Khalin (2022) mention that gamification through digital platforms gives the student more time to interact. If they receive immediate feedback, it engages them more to continue learning.

Game-based learning is another differentiator proposed by Lëttëra. This methodology has an impact on the students' motivation, making the didactic model more meaningful and positioning the young person as the protagonist of the learning (Cueva Gaibor, 2020).

The gamification in the web platform Lëttëra consisted of a process in which there are game rules to achieve the challenges of obtaining the highest number of badges. Each student can engage with each challenge twice. Also, this is displayed on a map that displays the progress in each challenge (reading exercises), encouraging continuous improvement through feedback presented at the end of each challenge. The texts of the reading exercises were selected according to different areas of knowledge and in other formats, as established by PISA, continuous and non-continuous texts (INEE, 2018). The various topics presented in the texts allowed students to learn about different social, economic, and cultural issues according to the type of text, thus linking reading with the context of real life in a gamified environment.

2.5. Metacognition

The concept of metacognitive monitoring emerged in the 1970s. Pioneering work on metacognitive monitoring by John Flavell determined the stage of this construct by describing the development of aspects of how a person reflects or thinks about their cognition (Crespo, 2000). Flavell defined the concept of metacognition as

"thinking about thinking." He divided the idea of metacognition into four main aspects: metacognitive knowledge, metacognitive experience, objectives or goals, and strategies.

At a broad level, the basis of metacognition is in the individual's mind. Metacognition has been positioned as Moshman (2008) classified as endogenous constructivism. Metacognition relates to the abstract reflection of new or existing cognitive structures. In this sense, metacognition emphasizes learning development rather than the learner's interaction with the environment (Dinsmore et al., 2008).

The intention of the Lëttëra web platform to contribute to the development of students' metacognition is a priority to equip them as critical readers who can transfer these skills to other learning areas or situations. By visually providing different colored underlining according to the cognitive processes proposed by the PISA test. This test evaluates the cognitive processes: locating information, understanding, assessing, and reflecting. For each of these three classifications of cognitive processes, a different underline color was assigned to allow the student to visualize the other cognitive processes to respond to the reading comprehension exercise in the text.

The design of the items is considered a predominant cognitive process to determine the correct answer. Once the students had completed the entire reading exercise, feedback was provided for each item. It explained how the cognitive process was a determining factor in selecting the correct answer to each item. In this way, the students could monitor their cognitive process and reflect on how they read, building their metacognition as they progressed through the Lëttëra challenges. The cognitive processes exposed visually through the underlining were a constant that led to the familiarization of these aspects that we sometimes do automatically.

3. Methodology

This research corresponds to a quantitative, exploratory, descriptive, and quasi-experimental study in which a technological innovation based on games is used to develop reading skills. A standardized test was used to analyze the study variables, and a descriptive analysis was carried out of the results obtained before and after using the educational innovation.

This project was part of the Novus projects and was selected to fund and support the development of the platform for reading skills. Novus is an initiative of the Institute for the Future of Education that seeks to strengthen the culture of educational innovation based on evidence from the professors of the Tecnológico de Monterrey (Portuguez-Castro et al., 2022). As part of their impact measurement strategy, the faculty is trained and mentored to submit a research protocol for approval. Due to the amount of projects supported by the initiative, they have worked closely with the ethics committees to ensure that Novus protocols follow federal and international regulations in regards to research subjects and their integrity. During training and follow-up, Novus Mentorship team ensures everything from methods to ethics is considered in the submission. If this is the case, the proposal is approved by Novus and faculty may begin to work on their project.

The technological innovation of the web platform Lëttëra aims to create a virtual space to develop autonomy through a gaming environment, asynchronously read, and receive immediate feedback. This innovation uses a user-friendly interface with stimulating aspects that optimally favor teaching-learning. In addition, the teacher benefits from the reduction of revision work since the tool monitors the management of each student's level, administering the exercises, evaluating, and providing feedback; thus, the student manages their learning progress.

The research seeks to analyze how technology used in game-based learning helps to visualize metacognition and makes the development of critical thinking necessary for reading literacy friendly and self-manageable. This analysis was based on a comparative analysis of the Planea 2017 test results to assess the learning and development of a life skill such as reading literacy. Specifically with the OECD's perspective, through the PISA Test, "reading should therefore be considered through the various ways in which citizens interact with texts on various devices and how reading is part of lifelong learning" (OECD, 2018, p. 8).

3.1. Procedure

The experiment consisted of several phases. The first was administering the Planea test 2017 as a diagnosis for students before using the platform. In the second, Lëttëra was implemented in the classroom using autonomous, flexible, and enjoyable learning technology. In the third phase, the results were evaluated through a second application of the test to assess the data obtained comparatively and by cognitive processes. The data was collected through an online form before and after completing the activities on the platform. Once collected, the data was anonymized and analyzed as a whole to protect the identity of the participants. Data collection was done prospectively during the semester in which the educational intervention was carried out.

3.2. Participants

The participants in the sample were 149 first-semester students of the Eugenio Garza Lagüera High School of the Tec de Monterrey. This institution is part of a system of 26 high schools, professional and postgraduate campuses, distributed throughout Mexico. The following three types of baccalaureates are offered: bicultural, multicultural, and international (32). The inclusion criteria of this study were: (1) students who are currently enrolled in a high school program; (2) students who are willing to participate in the study and provide informed consent (and, if under 18, have parental/guardian consent), (3) students who meet the specific demographic or academic requirements of the study (e.g., age range, grade level, specific courses taken). The exclusion criteria were: (1) students who are not fluent in the language of instruction (if applicable), (2) students who do not complete the informed consent. They had been previously enrolled in private junior high schools in the metropolitan area of Monterrey, Mexico, and had upper-middle-class backgrounds. Of these 149 students, 78 are male, and 71 are female, between 15 and 17 years of age.

3.3. Instruments

The Planea 2017 test is an objective, standardized test aligned to the Common Curriculum Framework, particularly in the fields associated with the Language and Communication and Mathematics competencies for students in Mexico. It is a validated and standardized multiple-choice instrument and consists of 100 items: 50 for Language and Communication and 50 for Mathematics (Planea, 2022). Its objective is "to determine the extent to which students achieve mastery of a set of essential learning at the end of the different levels of compulsory education" (Planea, 2022, p. 9), reading comprehension, reading literacy and mathematics, through the formative field of Language and Communication.

Planea test evaluates the use of two cognitive processes: the first is reading competence, which comprises: (a) the extraction of information, (b) the development of a global comprehension, (c) the development of an interpretation, (d) the analysis of content and structure as well as: (e) critical evaluation of the text; and the second process, which assesses reflection on language, consisting of (a) semantic reflection, (b) syntactic and morphosyntactic reflection, (c) linguistic conventions and finally, (d) knowledge of sources of information. The validity of the test has been established through a thorough review of the test's content and structure by experts in the field of education. As for reliability, the test has been subjected to statistical analysis that has demonstrated adequate internal consistency and acceptable inter-rater reliability, suggesting that the test provides consistent and accurate results (INEE, 2018).

The Language and Communication competence assess learning related to cognitive processes and knowledge for the selection, comprehension, and interpretation of texts with different characteristics, purposes, and thematic axes: argumentative, expository, and literary texts, in their continuous (text) and non-continuous (text and image) modalities, to know the mastery of the set of essential learning in this competence. The test comprises four categories: expository text, argumentative text, literary text, and construction of information, measured at four levels of achievement. These levels are described in Table 2.

The development of reading literacy in students was determined through the comparative analysis of the quantitative results of the Planea 2017 test between the initial and final application.

3.3.1. Programme for international student assessment and Planea achievement levels

The PISA test presents eight levels of achievement, from 1c to 6, in three different processes: locating information, understanding, evaluating, and reflecting. The Planea test presents four processes for reading literacy: extracting information, overall understanding, developing an interpretation, and analyzing content and structure.

The Planea Level IV correlates with PISA levels 3 and 4, specifically concerning interpreting the meaning of the nuances of language in a section of the text, demonstrating understanding in interpretive tasks, and comparing perspectives and drawing inferences based on diverse sources (National Commission for the Continuous Improvement of Education, 2018). The Lëttëra web platform focuses on the first PISA achievement levels (1c to 3), which correspond to level IV (the highest) of the Planea test.

3.3.2. Satisfaction survey

A survey was designed to determine the students' motivation to use the Lëttëra platform. The questionnaire consisted of 17 closed questions in which they answered "true," "false," or "doubtful" according to their perception of the exercises and their experience with the tool. Two questions were included to identify the age and gender of the student. Fifteen closed questions would assess if they felt an impact on their confidence in reading; if using the platform motivated them to read; if the interface and the methodology used made reading easy; and if they considered it appropriate to improve their reading comprehension.

The student satisfaction survey was validated by Spanish language teachers and an education researcher to ensure the quality and reliability of the obtained results.

3.4. Description of the Lëttëra platform

Lëttëra aims to develop reading skills in young people in upper secondary education. It comprises 12 reading comprehension exercises containing literary texts and academic, journalistic, and popular science articles. These texts allow users to explore different topics, expand their vocabulary, and above all, understand, interpret, analyze, and extract information from these texts that students are

TABLE 2 Achievement levels of the Planea 2017 test (INEE, 2018).

Level of achievement	Descriptor
IV	They select and organize relevant information from an argumentative text; identify the author's position, interpret information from argumentative texts (such as critical reviews and opinion pieces) and infer paraphrasing from an expository text (such as a popular article).
III	Recognize in an opinion article: purpose, argumentative connectors and constituent parts (thesis, arguments and conclusion); identify the differences between factual information, opinion and the author's assessment; identify the different ways in which written language is used according to the communicative purpose and use strategies to understand what they read.
II	They identify the main ideas that support the proposal of a short opinion article, discriminate and relate timely and reliable information, and organize it based on a purpose.
I	They do not identify the author's position in opinion articles, essays or critical reviews, nor do they explain the information in a simple text in words other than those used in the reading.

FIGURE 1
Home page of the Lëttëra web platform.

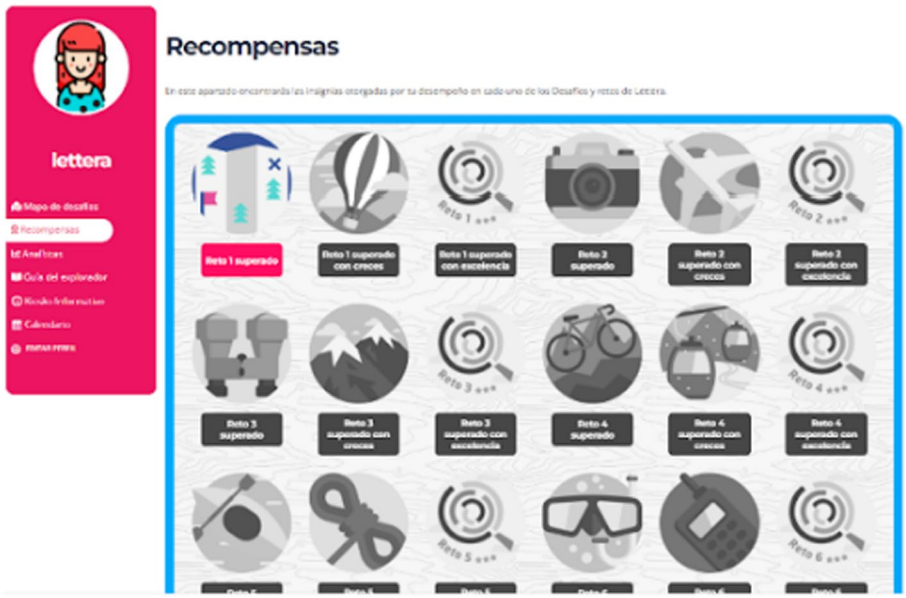

FIGURE 2
Explorer's guide, explaining the rules of the game.

likely to encounter at school and in their daily lives. Figure 1 shows the homepage of the platform.

3.4.1. Exercise examples

"Explore reading" is a core part before starting the exercises, in which the students are guided through highlighting and comments designed to enhance their critical reading skills, which help to foster metacognition and help students become critical readers, according to the PISA descriptors. These processes are color-coded, where green represents the cognitive skills of locating information, blue highlights those of understanding, and orange identifies skills related to reflection and evaluation, as well as the achievement levels of the Planea test.

Several game-based strategies were made to design a more entertaining environment within the platform; learners can choose their profile picture or avatar.

The texts are divided into three modules: mountaineering challenge, aquatic challenge, and countryside challenge, each with four challenges with reading comprehension exercises to visualize their progress on an interactive map.

3.4.2. Rewards system

The user's effort is rewarded through a game system, which is explained in the "Explorer's Guide" section (see Figure 2). Each player has two opportunities to tackle the reading comprehension exercise. If

they get 100 points when they engage in the challenge at the first opportunity, they obtain two badges and the logo of Lëttëra, which are then colored in the "Rewards" section. If students obtain a total of fewer than 100 points but more than 70 in the first opportunity, they can: (1) engage in the reading again or (2) keep the score achieved and get two badges; if they do not pass at the first opportunity, they can do it again, and if pass (or score higher than 70) get a badge; in case they make the second attempt and do not pass, students do not obtain any badges and must move on to the next challenge with the highest score achieved.

Once each challenge or reading comprehension exercise has been completed, Lëttëra provides the user with feedback on each item, which presents the process (locating information, understanding, reflecting, and evaluating). It also indicates the correct answer, explaining why each one is in that status, intending to induce personal reflection so that learners understand what an optimal reader needs to focus on and to self-direct their learning.

The platform also has a menu that allows the learner to view: the Challenge Map, Rewards, Explorer's Guide, Info Kiosk, Calendar, Edit Profile and Analytics, where they can check the score obtained in each of the challenges.

3.5. Data analysis

The data collected in the instruments were analyzed using descriptive statistics, graphs, and tables to present the results for each category. The total data from the Planea test were reviewed to examine whether there was a change in reading literacy results after using the Lëttëra platform. For this, the correct answer for each question in each of the applications was identified. The mean difference was then determined to establish whether there was a significant difference in the test results. The results were analyzed using Excel and Minitab v.21. The paired samples *t*-test was applied, given that the data came from the same subjects after the treatment (Johnson and Kurby, 2016).

The other analysis performed was for each sub-competence measured in the PISA test, for which frequency distributions and percentages were performed (Hernández Sampieri et al., 2014). Finally, the results for each participant group were compared to identify whether there were significant differences in the results obtained in the post-test after using the platform. The satisfaction questionnaire was analyzed with descriptive statistics to identify the most relevant aspects of the student's opinions of their experience with Lëttëra.

4. Results

The results of the study aimed to answer the research objectives. For the first objective: "Analyze how the use of technology in the form of games can improve the reading competence of high school students in Mexico," the Planea test was applied as a pre-and post-test to identify the learning gain of students due to the intervention with the platform. For the second objective, "Evaluate the impact of the use of the web platform Lëttëra on the reading competence of students," the results of the different categories of the test were analyzed, and the ones that had the greatest changes were determined. Finally, for the third objective "Identify how students perceive the use of technology in reading learning and whether this affects their motivation and satisfaction with the learning process," a satisfaction survey was applied to learn the students' opinions on the impact of the use of educational innovation on their motivation.

4.1. Planea test

The Planea test is a standardized test consisting of 50 items for the subject of Spanish. The research included using this test as a diagnostic tool before students engaged in using the Lëttëra platform. It was also used after their experience to analyze the changes in reading skills that could be attributed to this educational innovation. These results aimed to contribute to the objective of analyzing how the use of technology on the platform improves the reading competencies of students.

The results of the first application of the test are shown in Figure 3. The number of students that completed the test was 149. The maximum score for the test was 50 points, the minimum score was in the range of 13–17.5 correct answers (3 students), and the maximum score was 44.5–49 (7 students). Most of the correct answers ranged from 26.5–31 (40 students) to 31.5–65.5 (40 students). The mean was 31.436, with a standard deviation of 6.890.

In the second test implementation with the same number of responses as the previous application, the minimum score was 18–22.2 (8 students), and the maximum score was 50 (1 student) (Figure 4). The highest number of correct answers was concentrated within the 34.8–39 range (46 students). The mean was 33.255, with a standard deviation of 6.396. The number of correct answers above 30 increased from 91 in test 1 to 104 in test 2.

When comparing the means of the two groups, a difference of 1.82 was identified, showing that their overall results were higher after using the Lëttëra platform. Applying the paired samples t-statistic with a confidence level of 95%, a value of p of 0.004 ($p < 0.05$) was obtained, indicating that there was a significant difference in the student's scores when using the platform.

4.1.1. Analysis by student group

The results analyzed correspond to 149 student responses divided into six groups. The distribution of the groups is shown in Table 3. When comparing means for groups A, B, C, and E, there was a decrease in the score between P1 and P2 between −0.11 and-3.05. When applying the statistical test, it was determined that there were no significant differences in these groups, so there was no evidence

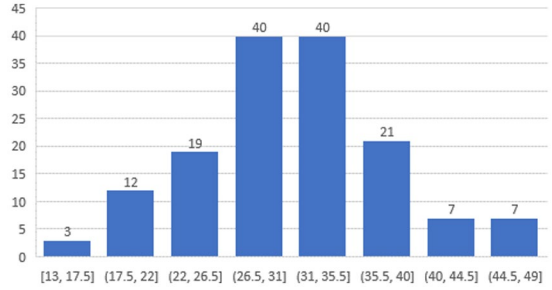

FIGURE 3
Distribution of Planea 1 test scores.

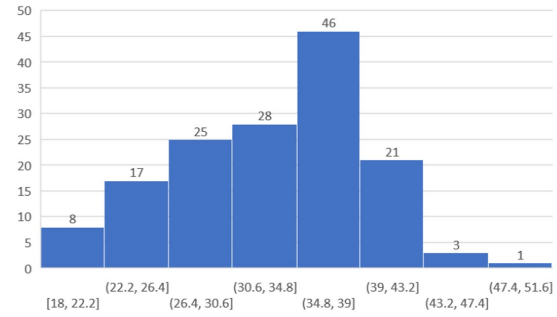

FIGURE 4
Distribution of Planea 2 test scores.

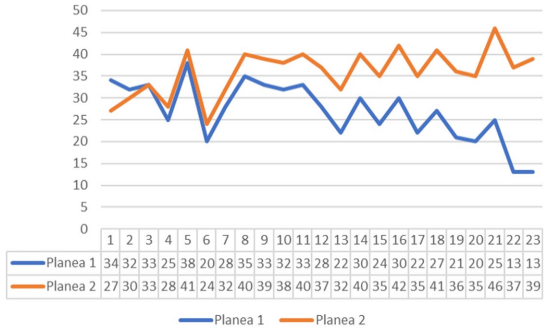

FIGURE 5
Differences in scores obtained in group D.

TABLE 3 Differences between study groups.

Group	*N*	P1 (Mean)	P2 (Mean)	Difference (av1-av 2)	*p*-value
Total	149	31.436	33.255	1.82	**0.004**
111	29	30.86	30.59	−0.27	0.819
112	26	29.88	29.77	−0.11	0.922
114	19	35.37	32.32	−3.05	0.148
116	23	26.87	35.96	**9.09**	**0.000**
414	32	35.88	35.72	−0.156	0.843
419	20	28.70	35.50	**6.8**	**0.000**

The values in bold are the significant results in the study.

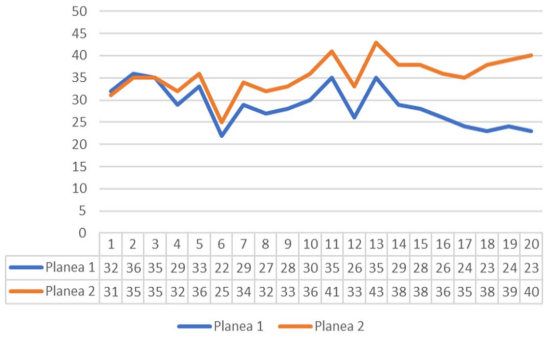

FIGURE 6
Differences in scores obtained in group F.

of an effect of the educational intervention in this sample. On the other hand, there was a significant difference of 9.09 ($p = 0$) in group D and 6.8 ($p = 0$) in group F.

In group D, there was a significant improvement in the mean score of 9.09 with a $p = 0.000$ ($p > 0.05$). As shown in Figure 5, most of the students in this group improved their scores after the educational intervention (87% of the students improved in the number of correct scores).

Group F also showed significant improvement in their results, with an increase in their scores of 6.8 with a $p = 0.000$ ($p > 0.05$). Students also improved in most of the questions in the second test application, as shown in Figure 6 (87% of the students improved in the number of correct answers).

When looking at the results per student, it was found that the students with the greatest improvement between the two tests belong to these groups (D and F). Student 1 obtained 26 points, student 2 of 24, and student 3 of 21. (These three students belong to group D); student 4 from group F improved by 17 points between P1 and P2.

4.1.2. Analysis according to the categories of the Planea test 2017

As mentioned above, the results of the Planea 2017 test were analyzed according to the four categories: information construction, argumentative text, expository text, and literary text. These results aimed to contribute to the objective of evaluate the impact of the use of the web platform Lëttëra on the reading competence of students. In the first test administration, the data allowed for a diagnosis of students' prior knowledge. Students were most successful in the questions related to identifying expository texts (72.67%), followed by identifying literary texts (64.90%), information construction (64.32%), and finally, identifying argumentative texts (63.03%).

In the second application of the test, students scored the highest percentage of correct answers in the identification of literary texts (69.60%), followed by expository text (67.42%), construction of information (65.25%) and argumentative text (62.90%).

The difference between the two administrations of the test was higher in the literary text category, with an improvement of 4.70%, followed by information construction (0.93%). However, there was no improvement in the argumentative and expository text; in fact, there was a decrease in the student's performance in these skills, as shown in Figure 7.

For each level of achievement according to the Planea 2017 test, it was possible to identify that for test 1, the level of students was higher in the category of Expository text, reaching 85.6% in level II and 79.19% in level III of the same category, followed by 70.28% in level III of Information construction. The lowest levels in this first diagnosis were level IV of the Literary category construction (43.46%), level IV of literary text (57.94%) and level IV of argumentative text (58.17%).

In the second test, the students continued with higher results in level II of the expository text category (75.50%), followed by level III of literary text (70.18%) and level III of argumentative text (69.80%). In this last category, they followed with a low result for level IV, with a percentage of 44.52%.

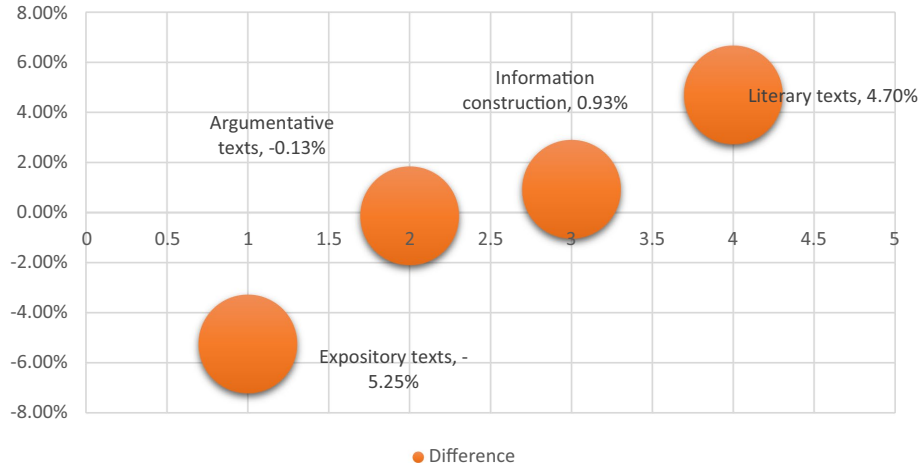

FIGURE 7
Differences in results P1 and P2.

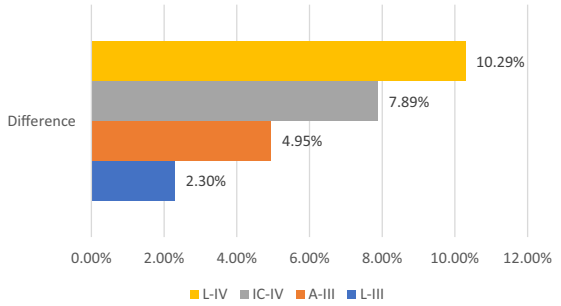

FIGURE 8
Differences in P1 and P2 tests by level of attainment.

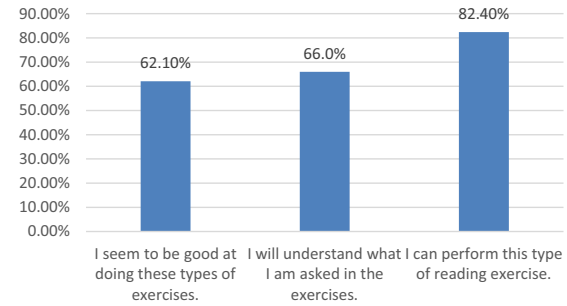

FIGURE 9
Responses related to self-confidence towards reading processes.

When comparing both results, it was observed that for the category of Literary text (L-III), students had an improvement of 10.29% in the achievement of level IV (A-IV) when retaking the test after the educational intervention, as well as in level IV Information Construction (IC-IV) (7.89%). There was also an improvement of 4.95% in the results of level III in the argumentative text category (A-III). The results are shown in Figure 8.

4.2. Satisfaction survey

The satisfaction survey was analyzed descriptively to identify the highest response rates for the following categories: self-confidence, motivation, interface, methodology and reading comprehension. These results aimed to contribute to the objective of identify how students perceive the use of technology in reading learning and whether this affects their motivation and satisfaction with the learning process. A survey was conducted among 149 students who, in the semester of August–December 2021, used the Lëttëra web platform, of whom more than 93% were aged 15–17, 53.6% were male, and 46.4% were female.

The survey asked about students' self-confidence in the reading comprehension process. Most of the students considered that they could do the exercises (82.4%) and that they were good at answering questions about lectures (62.1%) and that they would understand the exercise questions (66%). The results are shown in Figure 9.

The interface makes it easy for the students to engage in lecture exercises (75.8%), and most consider entering Lëttëra because it is not complicated (62.7%). When asked questions about the methodology, we identified that the most positive feature they found in the platform was the support they found the platform whenever they felt lost. Reading the highlighted parts and the text indications helped them better understand (80.30%). They liked the design, rewards system, possibility of selecting a profile, and map (73%). They also acknowledged a challenge in the questions, as only 28.70% answered them correctly on the first try (see Figure 10).

46.4% of the respondents considered working on the platforms' activities motivating; 39.2% indicated that they would learn how to read with this platform, and the majority believed that they have high expectations of how the platform can help them improve their reading (57.90%). A high percentage of the students considered that their reading comprehension level increased with Lëttëra (77%), as shown in Figure 11. Overall, 60.10% rate Lëttëra as "good," 28.80% as "excellent," and 11.10% as "fair."

5. Discussion

Developing reading competence is crucial for high school students, as critical readers must possess a considerable amount of knowledge and skills, such as observation, identifying details, relating ideas, comparing, contrasting, and inferring. The cultural context also influences the reading process. Therefore, it is essential to innovate and bring about cultural change in Mexico (INEE, 2018, p. 6). One critical way to promote this cultural change is through implementing reading programs in schools that focus on providing students with the tools they need to become better.

In this sense, this research aimed to propose an educational innovation based on gamification that would allow students to develop reading competencies through exercises that facilitated their achievement. The study's first objective was to analyze how the use of technology in the form of games can improve the reading competence of high school students in Mexico. It was observed that after using the platform, students had higher scores on the test. As in other studies, this suggests that incorporating technology in the form of games into reading learning can be an effective way to enhance students' reading competence (Hüseyin et al., 2020). The use of interactive and engaging activities can capture students' attention and motivate them to learn, leading to better performance on assessments (Chans and Portuguez Castro, 2021).

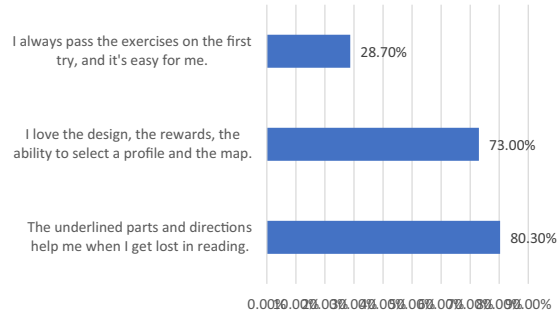

FIGURE 10
Responses on the methodology used in the Lëttëra platform.

For the second proposed objective, evaluate the impact of the use of the web platform Lëttëra on the reading competence of students, the study found that using the web platform Lëttëra had a positive impact on students' reading competence. Specifically, it was observed that students showed improvement in literary text comprehension and information construction skills. This could be attributed to the platform's accompanying comments being directly related to PISA processes and established levels for each skill. Another element to observe is that in the part of Explore reading, previous knowledge about continuous texts (argumentative, expository, literary), mixed texts (posters, receipts, infographics, among others), are strengthened Overall, this finding suggests an enhancement in metacognition among students which can help them understand and interpret different types of texts in various situations while promoting meaningful lifelong learning as pointed out by Dinsmore et al. (2008).

For the objective of identifying how students perceive the use of technology in reading learning and whether this affects their motivation and satisfaction with the learning process, it was found that most students considered that using the platform improved their level of reading comprehension and found it friendly and easy to understand. Most of the students responded positively to the platform's design, rewards system, profile selection, and progress map, and mentioned that their educational experience on the platform was favorable. This is considered to be due to another differentiator proposed by Lëttëra, which is learning based on games; this has various repercussions on students' perception of the task to be performed and their motivation, making the didactic model more meaningful and stronger in less time, positioning the young person as the protagonist of learning (Cueva Gaibor, 2020).

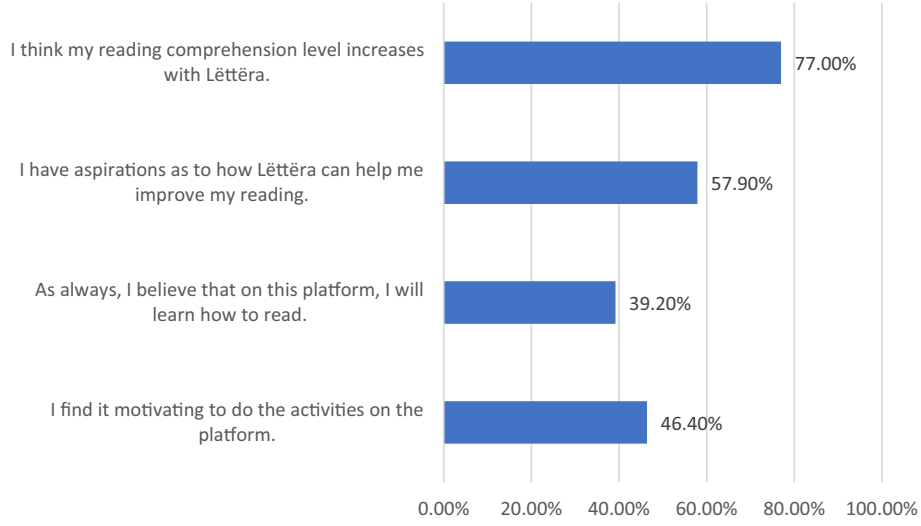

FIGURE 11
Students' motivation to use the Lëttëra platform.

6. Conclusion

In conclusion, the study shows that incorporating technology in reading instruction, particularly using web platform Lëttëra, can have a positive impact on students' reading competence and motivation. The novelty and significance of a study that concludes that incorporating technology in reading instruction, particularly using the web platform Lëttëra, can positively impact students' reading competence and motivation, lies in its ability to make the didactic model more meaningful and stronger in less time by presenting comments related to established levels for each skill and learning through games, positioning the student as the protagonist of their own learning.

Another aspect is that game-based learning presenting the exercises twice, the reward system, the immediate feedback, the progress map, and other playful elements increase motivation for learning. They foster an active environment to develop skills, making the reader optimally equipped to handle reading. In this sense, even though much remains to be done, it is necessary to continue innovating and applying the knowledge acquired over time in projects that use technology and game-based learning. To respond to the needs of the new generations who interact with these tools in other contexts daily and to promote further education that synthesizes the reading process through technology and is a means of self-managed practice to develop reading skills. However, further research is needed to determine the long-term impact of using technology in reading learning and to identify the most effective types of games and activities for improving reading competence.

For future studies, it may be interesting to investigate the long-term effects of incorporating technology in reading instruction on students' lifelong learning and their ability to transfer acquired skills to other areas of their academic and personal lives. We also suggest conducting more qualitative studies that allow for a deeper understanding of these learnings. Furthermore, future research could also explore how the use of technology in reading instruction can be adapted for students with different learning styles or those who may require additional support or accommodations. This study can be useful to educators, curriculum developers, and policymakers who seek to improve reading instruction through the integration of technology in their teaching practices.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

EL, CG, XC, and MP-C contributed to conception and design of the study. EL, CG, and XC organized the database. MP-C performed the statistical analysis. EL, CG, XC, and MP-C wrote the first draft of the manuscript. All authors wrote sections of the manuscript, contributed to the manuscript revision, read, and approved the submitted version.

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Conflict of interest

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

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Teaching computer programming: impact of Brown and Wilson's didactical principles

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This research studies the effects of the application of didactics to the teaching of computer programming, focusing on programming skills in the Python computer language. The problem arises from the failure and dropout rates of students in computer programming in computer science careers in INACAP and the consequent interest in promoting better learning. The general objective is to study the effects of an innovative methodology, based on Brown and Wilson's didactic principles, on the teaching process of Python programming in computer science students at INACAP. The theoretical framework is based on the didactics of teaching computer programming and the concepts of computational thinking skills of various theoretical references, and in particular on the didactic principles of Brown and Wilson. This research is carried out with a quantitative methodology of explanatory scope and with a quasi-experimental design, with a purposive sample, for the experimental stage the sample will consist of 100 first year undergraduate students of Computer Science, of which 50 will be the experimental group and 50 will be the control group. The hypothesis proposed is that "The students in the experimental group obtain a higher performance when applying Brown and Wilson's didactic principles than the students in the control group who are taught in a traditional way." The data collection technique used will be a 45-question multiple-choice test. The data analysis will be performed by applying statistical criteria, comparison of means and variances, among others.

KEYWORDS

computer programming, algorithm, didactics, evaluation instrument, didactical principles

1. Introduction

Since its beginnings in the 20th century with the theoretical conceptualization by Alan Turing of a machine capable of making calculations and with memory to store data, computing has led us in a spiral of technological advances, which has evolved exponentially. The Englishman Alan Turing was the founder of Computer Science, he was a mathematician, philosopher and cryptographer, a visionary of his time. Turing lived from (1912 to 1954). It should be noted that, without that initial idea and the construction of the first computers as electromechanical machines, computing would not be what we know today (Kulkarni, 2015).

In this context, computer science has evolved during the second half of the 20th century, starting with computer programming in assembler through procedural languages to focus at the beginning of the 21st century on Object Oriented programming and code generators. Currently there are several initiatives in the world to incorporate programming in schools, one of them is the Bebras challenge, which is aimed at motivating, practicing and evaluating the skill levels of students at an extracurricular level. Along with the Bebras challenge is the initiative called https://code.org/, which provides free material to anyone who requests

it, in order to facilitate access to computer programming teaching material. There is also the NGO https://www.ideodigital.cl/, which provides free curriculum materials for schools, including teaching materials and associated assessment tools. But let's see what each of these initiatives is.

The Bebras Challenge (https://www.bebras.org/) is a community computer education network that was born in Lithuania in 2005 and has been consolidated in more than 40 countries to discuss computer science concepts for school computer education. The Bebras algorithm development workshops, which have been organized annually since their inception, bring together representatives from all these countries for rigorous work and decision making on good tasks to promote computer education in schools. On the one hand, the Bebras challenge is an international assembly driven to respond to the needs of computer education worldwide, and on the other hand, almost all activities are nationally based, organized by communities in the participating countries. Bebras is an attractive way to promote computer science learning worldwide. It has a community-based, distributed organization, which makes it a democratic organization, as everything comes from the bottom up. The workshops work as extracurricular activities so participants do it voluntarily and based on their motivation to learn (Dagiene and Stupuriene, 2016; Araujo et al., 2019).

Regarding the NGO Code.org is a non-profit organization dedicated to expanding access to computer programming in schools and increasing the participation of all who need and want to learn to program computers. Code.org's vision (www.code.org) is that every student in every school can learn to program and that this learning is free for those still in school. Code.org, the leading distributor of school computing curriculum to school communities in the United States, also established the annual "Hour of Code" crusade, which has reached more than 15% of all school children worldwide (Kale and Yuan, 2021).

Ideodigital is a national initiative originated thanks to a strategic alliance between the Kodea Foundation (www.kodea.org) and the BHP Foundation (www.bhp.com), which seeks to create the necessary conditions for thousands of children and adolescents to become protagonists of the digital society of the 21st century, incorporating computer science in the Chilean public school system. The purpose is to create awareness in the actors of the educational community about the benefits and feasibility of the application of computer science in the public school system. It also promotes the implementation of computer science in the classroom, for which it develops curricular courses from the first year of primary education to the fourth year of secondary education, which are available as a public good for the entire school system, articulating an ecosystem to train and accompany teachers and develop a network of leading schools in the teaching of computer science, which by July 2022 there were more than 80 schools that have already joined the ideodigital system (www.ideodigital.cl).

At present, there are several problems for the implementation of the teaching of computer programming in schools, which begin in the political discussion of the countries and the sufficient budget allocation to equip the educational system with an adequate number of computers in laboratories suitable for teaching. After overcoming the issue of computer infrastructure, an additional problem arises, which is the availability of a sufficient number of teachers properly trained to teach programming. In this sense, the political discussion will begin when a diagnosis is made about the implications of the advance of technology and how it could displace a significant percentage of workers (due to the automation of work) and with it an increase in unemployment that will imply socio-political instability, which will shake the economy and governments that are not properly prepared for these changes. Once the first barrier is overcome, the implementation will come, which would imply an operational diagnosis, how many trained teachers exist, how they are distributed in the country, also regarding digital infrastructure, laboratories, software, etc. (Belmar, 2022).

1.1. Context of programming teaching

Already at the beginning of the 21st century, computing is ubiquitous, filling every space, ranging from a system that allows programming a microwave oven to a complex Artificial Intelligence system that is capable of driving motor vehicles without endangering the safety of people, animals and property. In this context, in developed countries it has been defined that the XXI century is where work, economy and social relations are and will be guided by a new type of skills of people, which has been called computational thinking, which is constituted by the cognitive skills of; abstraction, decomposition, algorithmic thinking, debugging and problem solving. In addition, it has been proposed by several researchers that these skills are transferable to other areas of knowledge, such as natural sciences, mathematics and history (Wing, 2006).

It should be noted that the present research is oriented to implement a didactic strategy in the teaching process of computer programming, since until now the application of didactic strategies in the teaching of programming is unknown, which occurs for several reasons; on the one hand, the area of teaching programming (in schools) is incipient, so didactic theories for teaching programming have not been developed, or because the teachers who teach programming do not have pedagogical training, which in some cases are professional disciplines such as Computer Engineers or Electronic Engineers or other equivalent professionals with training in some computer programming language, so it has been naturalized that each teacher teaches the way he or she has learned in his or her own professional training. The following are some references on the teaching of programming in computer science courses in the first year of study in higher education.

1.2. A case from the University of TI West, Denmark

Bennedsen and Caspersen (2007) conducted a survey in 63 universities in various countries to estimate the failure rate of the subject "introduction to programming." In this regard, the research states that a common conception of students is that computer programming is a difficult course and that failure rates are high.

The average failure rate for different types of initial programming courses was around 30%. Therefore, it is suggested that ACM Education (Association Computing Machinery Education) and other participants in the study done by TI West University, may conduct further studies with a larger sample in order to postulate more representative results (Bennedsen and Caspersen, 2007).

1.3. A view from Durham University in the UK

Watson and Li (2014) researchers at Durham University in the United Kingdom, calculated a high failure rate in the achievement level of students in the subject of introduction to computer programming. The study describes the results of 161 introductory computer programming courses that were conducted in 15 different countries, in which the average pass rate was found to be 67.7%, therefore, the average failure rate is 32.3%. However, despite several studies conducted on the topic of achievement level in novice first-year computer programming students, which cite a motivation for research on pass/fail rate, in introductory programming courses, most of the available evidence is still not sufficiently representative. In addition, it was found that the pass rate has been maintained over time, and that it does not depend on the programming language taught, nor on the professor, nor on the University Institution that teaches it and that the perception of students is that learning to program is a difficult task (Watson and Li, 2014).

The objective of this study is to study the effects of Brown and Wilson's didactic principles on the teaching process of Python programming in computer science students at INACAP. To achieve this objective, it was necessary to work hand in hand with the institution in order to involve the computer science area to carry out the experimentation, which was carried out during two semesters, first the validation of the test published in Belmar (2023), and then with that validated test, work with the teachers of the control and experimental group, so that they would take part in the research, taking the students the pre and post-test, necessary for the data collection and statistical analysis described in this report.

2. Theoretical framework

2.1. Generalities

While it is true that this research aims to study the effects of a didactic strategy for teaching computer programming, it is also true that the concept of "Computational Thinking" has taken some prominence whenever the topic of computer programming is addressed. What is happening is that the teaching of computer programming is being added for all students in school, with the idea of generating broad skills, which go beyond being educated in programming. Thus, learning computer programming is used as a scaffold for the development of computational thinking skills, which are transferable to other areas of knowledge, since they also radiate to the whole area of science and technology (STEM), including art (STEAM) (Rojas and Garcia, 2020).

According to Wing (2006), Computer Science is the study of computation, what is computable and what is not, and what is computable, how to do it? But to appropriate the concept, we will see other researches that consider studies based on computational sciences, which broaden their meanings based on their application. Some applications of computing can be named, such as; Internet of Things, social networks, big data, Artificial Intelligence, Robotics, Video Games, Communications, smart phones, augmented reality, virtual reality, among others. The truth is that computing is present in everything (Psycharis et al., 2020).

For García (2018), the digitization of information is the beginning in the digital edification that will energize the world of the 21st century. Given this, from which we cannot dissociate, schools must carry out activities with students to act in a virtual world, for which they must learn the language of this century, without which they will be catechized into digital illiterates. Therefore, schools must teach students the skills of computational thinking. In this sense, ICT training is absolutely insufficient, since what this century requires is to get the skills in computation, to adapt to a new way of solving problems and thinking. Therefore, the present challenge is to train young people to succeed in a digitalized world. That is, they must be trained in the new paradigm of computational thinking skills (García, 2018).

Complementing the above, from Lithuania in 2018, researchers Juškevičiene and Dagiene from Vilnius University, published the article "relationship between computational thinking and digital competence," which investigates both concepts, starting with computational thinking. It should be noted, the researchers report, that the European Commission's scientific center has been guiding member countries in the sense that computational thinking is the most important skill of the 21st century. But, despite the interest in implementing computational thinking in schools and public and private investment, there are a number of challenges to the integration of computational thinking into school curricula (Juškevičiene and Dagiene, 2018).

It should be noted that the teaching of programming should consider students' ability to develop algorithms that solve concrete problems. Regarding algorithms, these are finite sequences of instructions written in some language according to its syntax, whose instructions involve: simple step-by-step sequences, as when guiding a student on the steps to follow to solve a second-degree equation; sequences that consider cycles, as when elaborating an algorithm that allows calculating powers by multiplying the base n-times by itself; conditional sequences as when implementing a Taylor series of a trigonometric function such as sine or cosine. Thus when assessing students learning to program, it is key to consider branching instructions (if statement condition then ... else), defined cycles (for {sentence$_1$ ... sentence$_k$}), and conditional cycles (while condition {sentence$_1$ ... sentence$_k$}), being control structures a prominent part of the learning that students must acquire (Mühling et al., 2015).

Of the articles read, the contribution of Belmar (2022) is important in his publication "Review on the teaching of programming and computational thinking in the world," research in which he integrates modeling and simulation as basic skills of computational thinking, so that it incorporates designing problems, categorizing and studying data logically,

symbolizing data through models and mechanizing procedures. In this way, taking a look at teaching in schools, these skills enhance qualities such as: freedom to deal with complexity, perseverance in working with complex projects, tolerance of the fuzzy, and readiness for teamwork to achieve a common goal and report on it. Which is complemented by Grgurina (2021) who relates computational thinking in its main concepts, such as: "data collection, data analysis, data representation, problem decomposition, abstraction, algorithms and procedures, automation, modeling and simulation."

When confronting the achievements of countries in the teaching of computational thinking in schools, it is convenient to look at the development of nations in public policies that incorporate the subject in the mandatory curriculum, such as the case of England in 2013 and European countries since 2016, or other Asian states such as Japan, South Korea and China, in which computational thinking is understood as the skills of the XXI century and that will move investments in technology. However, in underdeveloped countries, whether in Latin America or Africa, the states have other priorities, so the issue is not the subject of political discussion, in this sense the teaching of programming remains in the hands of the initiative of individuals and lacks institutionalization and involvement in public policies that cement the creation of the necessary conditions for students to incorporate the skills of computational thinking in their knowledge (Belmar, 2022).

2.2. Didactics in programming education

2.2.1. Gamification: teaching through the use of games

The didactics based on the use of games helps in the students' willingness to learn, which in the field of computational thinking covers a larger area, ranging from the conception of the design idea, the construction and use of games. Gamification is also transversal to many areas of knowledge. Thus there are practices of the use of digital games in storytelling, in the practice in mathematics, in history, etc. Thus, de Paula et al. (2018)) in his work "Playing Beowulf: linking computational thinking, arts and literature through the creation of games," reading with that opens a game programmed by two 14-year-old students, "Playing Beowulf," which in collaboration with students from the British Library, a program in which 13–14 year olds from a London school learn, has managed to expand the scope of programming beyond the STEM area. The games are based on their unique understandings of the Anglo-Saxon poem Beowulf (de Paula et al., 2018).

In the USA, researchers from Carnegie Mellon University and Notre Dame, published in 2017 the article entitled "A computer game that promotes mathematics learning more than a conventional approach," which unveils a practical work that generates evidence that a mathematical educational game can help with learning alternatives, which manages to make learning mathematics more entertaining. The program "Decimal Point" is a single-player game that recreates the amusement park and is oriented to young teenagers. The program called "Decimal Point: the fantastic and fabulous world of fractional fun." The program is set up so that youngsters can jump in sequence to different themes (Haunted House, Wild West, Space Adventure, Amusement Park), playing a variety of small games in each theme area predestined to learn decimals. The youngster's progress is made through a sequence of steps in the park and players are graphically shown the next game (McLaren et al., 2017).

Similarly, a paper whose objective was to incorporate the computational thinking board game with robots so that students practice computational thinking skills as they complete the board game activities by controlling the action of the robots. The game teams are joined by two students in one team helping each other, those who played with the other team composed of two students. The work used Robots City board games to allow young people to learn the concept of computational thinking through game-based learning and use cell phone programs to command the actions of the robots (Zhou and Hsu, 2020).

2.2.2. Educational robotics

In teaching, the multimedia environment helps to lower learners' anxiety and provides a stress-free classroom environment. Also, multimedia materials collaborate with English instructors to promote students to perfect their English learning and decrease their language stress (Huang and Hwang, 2013 in Kong et al., 2020). As soon as students feel confident in the foreign language classroom, they lose inhibition and start speaking in the second language, the target language. The experiments reveal that, in the learning process, with the incorporation of robots, students speak English as a matter of course to command the robot. In addition, the research analyzed the behavior among the students and revealed that when the student is practicing oral English, there will always be other students to help him/her in his/her language practice, so if the student makes a mistake, there will always be someone to correct and guide him/her (Kong et al., 2020).

In another work at the Norwegian University of Science and Technology, children's teamwork and their creative disposition in programming games and educational robotics was investigated. The objective of the work was to investigate the teamwork driving qualities of children in programming activities. For this purpose, an experiment was designed with 44 students between 8 and 17 years old, who were programming for a whole day. Their programming work was guided and data was recorded such as; their look and attitudes in relation to their achievements, well-being, collaborative work, with post-activity tests. In the analysis of the data it was revealed that the behavior helps the relationship between willingness to learn, openness to teamwork, compliance - joy and learning achieved (Sharma et al., 2019).

In Taiwan researchers Jen and Hsu (2020), from National Taiwan University, in an investigation entitled "The impact of using mobile block-based programming to control robots with fifth grade students learning computational thinking in Singapore." The robots were configured in Chinese language to act with block-based programming. The experiment revealed that the students achieved significant improvement in both computational thinking learning and also in handling conditional sentences through the knowledge training tasks based on robot games (Jen and Hsu, 2020).

Finally, the authors Lee and Low (2020), implemented a computational thinking curriculum with robot programming

tasks. Also, Cheng et al. (2018) worked on an investigation regarding the fundamental applications of the educational robot, through a requirements analysis, seen from the eyes of experts and researchers. On SRA (Sence, Reasoning, Action) coding the authors Fanchamps et al. (2020, 2021), worked regarding the implication of SRA coding on algorithmic thinking. In addition, the implications of using cell phone applications to command robots with elementary school students in school was investigated (Yi and Ting, 2020 in Kong et al., 2020). Finally, researchers Souza et al. (2019), studied the implication of computational thinking in mathematics through robotics.

2.2.3. Metaphors and blocks for teaching programming

Pérez et al. (2018), propose using metaphors, such as; pantry/memory and boxes/variables. Thus, it shows the alternative of employing such metaphors to diverse resources that the teacher has access to. Four step-by-step guidelines are provided on the recommended way to use metaphors in class. In this sense, an opinion study was carried out among students, for which the opinions of 62 students from 9 to 11 years old and their teacher were collected. The study revealed that 65% of the respondents found metaphors useful. The children were proficient in understanding metaphors, and <10% of the children preferred direct language without using metaphors. In a conversation with him as a teacher, he reported, "I think it is correct, because the students are not only working with instructions in the recipes, but they are able to see themselves on the screen or on the board" (Pérez et al., 2018, 2020).

In another case, the AgentSheets program exchanged four alternatives to generate a block programming way. After initially locating on syntax alternatives, it has been tested with perspectives to go to the next step, semantics, to resolve meaning and practical conflicts. Three considerations are reported there: (1) Contextualized explanations to aid understanding, (2) Traditional programming to proactively encourage possible outcomes, and (3) Color palettes to make programming easier. The block programming community has been on the lookout for syntactic coverage of coding (Repenning, 2017).

2.2.4. Learning programming like learning a second language

Learning to code computers is undoubtedly a linguistic learning, since it is a way of communicating to the computer what to do and how to do it, and once it has finished how to elaborate the results and where to send them. Thus the lack of grammatical rules to get started in coding leaves students with a pedagogical fissure to achieve by their own means, although teachers expect to solve the exercises using concepts of logic mediated by a language in which many complicate him to say the elementary. So much so, that some more talented as to get their codings to work correctly stagnate in their learning during their first year. The exact complications of learning a programming language are similar with the complexity of speaking a second language (Portnoff, 2018).

Portnoff (2018) says that the 10 years he has been a teacher in an introductory computer programming course, he has used a diversity of programming languages, such as; Scratch, Alice, minecraft and others. However, the promising significance of software tools, what everyone remembered was the explicit language model. In recent years, it has become increasingly clear that implicit language strategies are critical. This is not to say that the explicit language model is ineffective: there are evidently talented learners who go on to train as expert programmers (Portnoff, 2018).

2.2.5. Other didactic initiatives in computer programming

In Germany in 2018, the book "Content and Skills of Computer Science" was published by the University Press of the University of Potsdam. In the first paper that is part of the publication, entitled "What everyone should learn about computer science: an analysis of University courses for students of other disciplines," professors Stefan Seegerer and Ralf Romeike from Friedrich-Alexander University propose a didactic way to be prepared for life in the digital society, this is not only because computer science is present in our lives in the productive area and in education, but also in all aspects of our daily lives. In their work they analyzed 70 modules on computer education for students from other disciplines; syllabi and lesson plans, identifying some key issues and types of tools used (Bergner et al., 2018).

2.2.6. Pedagogical models and didactics

For the purposes of this work, didactics is a science, so it has an object of study, since its purpose is to transpose academic knowledge into sufficient actions and nurtured holistic components coming from teachers, so that it makes sense to learners and allows students to appropriate new knowledge. There are didactics generated by areas and sub-areas of subjects; for example, there is a didactics of language, a didactics of geometry, a didactics of algebra, a didactics of chemistry, a didactics of physics, etc., Thus, what best generalizes didactics is what Shulman proposes about the didactic knowledge of content, as a methodology capable of making the teacher an architect of himself in his creations and practices rich in ways of teaching that allow students to move toward new knowledge in a pleasant, motivated and participatory way. Thus, the teaching of computer programming, as an emerging area still navigates on some postulates of didactics that have not been experimented and proof of this is that those who teach programming, are disciplinary professionals without pedagogical studies (Belmar, 2022).

For Ortiz et al. (2015) and his team, all researchers from the University of Magdalena in Colombia, published a research entitled "Pedagogical models from a psychological-spiritual dimension," in which they analyze pedagogical models, making a brief description of the behaviorist pedagogical model (Skinner), the constructivist pedagogical model (Piaget) and the sociohistorical-cultural theory (Vygotsky) as a pedagogical model. In addition, various holistic and ecological pedagogical proposals derived from new epistemologies are analyzed, such as Maturana's bio-pedagogical model, which proposes a biology of love as the ontological and epistemological basis of pedagogy. Every educational process has a method, an axis,

which directs and contributes to the development of the exercise of training, which we call pedagogical model (Ortiz et al., 2015).

Precisely, pedagogy is a science whose boundaries show its dynamics between society and human thought. A pedagogical model is a theoretical and practical plan of strategies that teachers and educational institutions possess to develop the training process of their students. The pedagogical model is characterized by the articulation of notions such as: curriculum, pedagogy, didactics, training, education, teaching, learning and evaluation; but it also contributes to the configuration of practice and theory. For the configuration and identification of a pedagogical model it is important, according to Coll (1991 in Ortiz et al., 2015), to answer five essential questions: why teach, what to teach, how to teach, when to teach, and what, how and when to evaluate (Ortiz et al., 2015).

For his part, Zipitría (2018), a research scholar at the Computer Science Institute of the University of the Republic of Montevideo in Uruguay published a research entitled "Piaget and computational thinking," a perspective that points in the same direction of the construction of computational thinking skills, both as a cognitive skill and the means by which this skill is built, which is computational programming. The publication discusses the concept of "computational thinking." Computational thinking is in a higher category than algorithmic thinking, however, the latter is the key piece from where computational thinking skills begin to be acquired, since the way of thinking when solving algorithmic problems and representing their solutions as algorithms, are characteristic of Computer Science (Zipitría, 2018).

The most relevant aspects of Piaget's theory is to look at and analyze the construction of knowledge as a process and to unveil how the transition from a lower level of knowledge to a more complex level takes place. In this expanded sense, the learning of computational thinking can be explained. The research methodology is supported by Piaget's application of Piaget to have students solve problems by sorting, counting and searching elements of data and reflecting on the method they employ and the reasons for their success (or failure), as a first step toward the conceptualization of algorithms and data structures. From this perspective, the author developed the extension of Piaget's postulates as the need to describe cases where the subject must instruct an action to a computer (Zipitría, 2018).

Researchers from Japan, investigated regarding pedagogical transformation based on student-led design and computational thinking. In current times that technology is everywhere it is appropriate to discuss transformative teaching where technology is part of who we are. We do not believe, say the authors, that we have any basis for claiming that the unification of technology happens by itself, for students performing complex robot coding activities, it was the redesign of didactics and learning by doing that made the real difference. The authors' current thesis points out that the idea of unification of information technologies, is slowly disappearing, and in its replacement is gradually integrating computational thinking with its associated skills (Vallance and Towndrow, 2016).

Grgurina's (2008) work is oriented toward the teaching of ICT (Information and Communication Technology), and develops experiences in the teaching of computing at a general level without pointing out didactics as the basis of teaching action to achieve student learning, and does not contain a didactic formulation of the teaching of computer programming in initial teacher training. It should be noted that Grgurina (2021), 13 years later, describes computational thinking in terms of its main concepts, such as: data collection, data analysis, data representation, problem decomposition, abstraction, algorithms and procedures, automation, simulation, and parallelization (Grgurina, 2021).

Also, Chinese researchers inquired about a mixed didactic method and fostering innovative aptitude, whose methodology of action is based on computational thinking. Computational thinking incorporates computational thinking and unification with the natural environment, which considers progressive thinking in computing environments. In the future, non-computer professionals can use computing to create and shape new ideas for multiple professions. In addition, they would be able to support other areas of research into new electronic equipment and software. Computational thinking can significantly collaborate diverse non-computing professionals to bridge the gap between knowledge construction and tool creation (Zhang et al., 2019).

Finally, the teaching of computer programming requires the use of computers, however, when there are no resources for it, it is possible to work in an unplugged way, which in reality is learning through a series of board games that seek to replace the use of a computer (plugged) in the teaching of programming. Thus, for example, the assignment of a variable is represented by the movement of a figure on a board, the conditional if is also represented by some different figure, and so on for the different operations and control statements of a programming language, such as the conditional *while loop {condition}*, the *repeat until {condition}* or the unconditional *for loop*. Once novices have achieved some learning in a unplagged way (without computer) then they are already moderately prepared to start learning programming on the computer, i.e., plugged (Grgurina, 2021).

3. Materials and methodology

3.1. Materials

The materials to carry out the present work consider having an office equipped with a desk with a personal computer with Internet connection, which is at least equipped with Office software and SPSS software (Statistical Package for the Social Sciences).

3.2. Methodology

The methodology of the study corresponds to a quasi-experimental design with pretest, posttest, and control group, and comprises a didactic intervention in 12 classes of Unit III of the subject "Introduction to Programming." The test data collection, data analysis and presentation of the results. The test consists of 45 multiple-choice questions, scored 0 or 1, depending on whether the answer is correct or incorrect, is attached in Supplementary Annex 1. The test was taken during class time, so it was carried out synchronously. See results of the pre- and post-test in Supplementary Annex 2.

3.3. Design guidelines and principles

- Objective: The objective is to determine the effects of applying the didactic principles of Brown and Wilson (2018) on the teaching-learning process of Python programming in computer science students of INACAP (National Professional Training Institute) in Chile.
- Construct definition: Programming in Python, implies the ability to solve problems based on computer science concepts and using the logical syntax of the programming language: basic sequences, loops, iteration, conditionals, functions, variables, and data structures such as arrays, tuples and dictionaries.
- Population: In the year 2021, 32,802 first year students of the computer science degree program at INACAP.
- Sample: The experiment was carried out with 100 students of the course "Introduction to Programming" in professional technical education, INACAP Ñuñoa branch.
- Type of test: multiple-choice test of 45 items with four answer options (only one correct) (Belmar, 2023).
- Estimated completion time: 90 min.

Didactics: Ten principles for teaching programming by Brown and Wilson.

Principle 1: Remember that there is no such thing as a programming gene. The first and most important tip is that there is no innate knowledge in computer programming. Computer programming skills are not innate, but rather a learned skill that can be acquired and improved with practice.

Principle 2: Use Peer Support. One-on-one tutoring is perhaps the ideal form of teaching; a teacher's full attention can be focused on one student, and they can fully customize their teaching for that person and tailor individual feedback and corrections based on a two-way dialogue with them.

Principle 3: Use live coding. Instead of using slides, instructors should create programs in front of their students.

Principle 4: Have students make predictions. When instructors use live coding, they usually run the program several times during its development to show what it does. The key to making demonstrations more effective is to have students predict the outcome of the demonstration before running it.

Principle 5: Use pair programming. Pair programming is a software development practice in which two programmers share a computer.

Principle 6: Use solved examples with labeled subgoals. Learning to program involves learning the syntax and semantics of a programming language, but it also involves learning to build programs. A good way to guide students in building programs is to use solved examples: step-by-step guides that show how to solve an existing problem.

Principle 7: Stick to one language. A principle that applies in all areas of education is that transfer only comes with mastery of a programming language. Therefore, courses should stick to one language until students have made enough progress with it to be able to distinguish the forest from the trees.

Principle 8: Use authentic tasks. Learners find authentic tasks more engaging than abstract examples. One caveat about the choice of context is that the chosen topic may inadvertently exclude some people while appealing to others.

Principle 9: Remember that novices are not experts. This principle is tautological, but it is easily forgotten. Novices program differently from experts and need different approaches or tools.

Principle 10: Don't just code. Design before coding.

Finally, for details on the 10 principles, go to the source found at Brown and Wilson's publication (Brown and Wilson, 2018).

4. Discussion

4.1. Global context of computer programming education

The teaching of computer programming involves resources ranging from the implementation of digital infrastructure (computers and software), the availability of sufficient human resources to cover the entire primary and secondary education, to the lack of didactics to guide the delivery of computer programming knowledge. In this context, the questions arise: what to teach and at what level? Which programming languages to teach; Python, Scratch, Alice or Java? In which subjects to incorporate programming? Only to teach in the STEM area or to extend to the humanistic area? In addition, there is the aspect of how to measure learning, how to know that what is done pays off in new learning for students and that this learning truly constitutes the acquisition of computational thinking skills (Belmar, 2022).

At the 21st edition of the "International Conference on Interactive Collaborative Learning" and the "47th edition of the International Conference on Engineering-Pedagogy" held in 2018 at the "Aristotle University of Thessaloniki of Greece," they published a text with the papers presented entitled "The Challenges of the Digital Transformation in Education," in which among the many papers presented, a section on research conducted on preschool, primary and secondary education stands out. Some of the titles observed are: "Cyber and Internet Module Using Python in Junior-High School," "Children's Reflection-in-Action During Collaborative Design-Based Learning," "Internet Addiction and Anxiety Among Greek Adolescents: An Online Survey," "Intelligent Robotics in High School: An Educational Paradigm for the Industry 4.0 Era," "Design and Use of Digitally Controlled Electric Motors for Purpose of Engineering Education," among others. It should be noted that, from the observed titles, didactic teaching strategies do not appear and neither are observed validations of tests to measure learning (Auer and Tsiatsos, 2019).

For its part, UNESCO proposes a master plan for the development of digital skills, in which in one of the sections it highlights some important points in which it points out that the plan should have described aspects on the technological infrastructure in the school, as a necessary prerequisite, teachers trained in the area of digital technologies, and the integration of digital technology within the curriculum, not only in specific courses but within the goals or objectives (Fau and Moreau, 2018). These aspects must be supported by public policies that guide in teaching methodologies and didactics, beyond providing digital infrastructure and human resources. It should be noted that implementing the teaching of computational thinking is an enormous task, which should start in universities by preparing teachers for such a gigantic task, who after the curricular policies

have been dictated by governments and the economic resources have been allocated, will be able to implement the new teaching in schools (Law et al., 2018).

This is complemented by the European Commission, which published in 2016 a paper entitled "Developing Computational Thinking in Compulsory Education," in which it makes various diagnoses and the state of progress in this area in the member countries. The research points out, among other things, that the states have the obligation to train the next generations to operate the new digitalized world that is approaching, however, the states that have implemented the changes in education have revealed the lack of teachers trained in Computer Science, and where they have them, although few, there is the problem that there are no pedagogical and didactic models for teaching the new skills. The report analyzes the most significant of the development of computational thinking for formal education in Europe and in sum shows the implications in the classroom and in the academy (Bocconi et al., 2016).

4.2. Results

A statistical test that validates the analysis of the results is the repeated measures factorial ANOVA (pre- and post-test), with the pre- and post-test treatment as an intra-subject factor and teaching method (traditional and innovated) as between-group factors. The pre- and post-test, being evaluated in the same subjects, is a repeated measure so it should be treated as an intra-subject factor, since these observations are not independent. Statistical analysis was performed with SPSS (Statistical Package for the Social Sciences) software version 29.0.1.1 under license from IBM (International Business Machines).

The repeated measures ANOVA procedure performs the analysis of groups of related dependent variables corresponding to different measurements of the same property at different times. In such an experimental design, the dependent variables correspond to measurements of more than one variable for different levels of within-subjects factors. For example, the score achievement and the time taken to respond may have been measured for each subject at two or three different times. The repeated measures ANOVA procedure provides multivariate analyses for repeated measures data. In addition to testing hypotheses, repeated measures ANOVA generates parameter estimates (Camacho, 2019).

In the tables below it can be seen that the tests of inter-subject effects give us a significance of 0.01, a value that is <0.05, a threshold that confirms that the results are statistically significant. In addition, the multivariate tests ratify the significance of the experiment and show a statistical power of 100%, that is, an observed power of 1.00. As shown in Table 1.

According to Camacho (2019) the statistics for multivariate tests with repeated factors are mainly; the Pillai trace which is a test statistic produced by a Multivariate Analysis of Variance (MANOVA), which is a value ranging from 0 to 1. The meaning is that when the Pillai trace approaches 1, the more significant is the evidence that the explanatory variable has a statistically significant effect on the values of the response variables. Another indicator is Wilks' Lambda which is the product of the unexplained variances in each of the discriminant variants, and the lower its value, the greater the disparity between the groups being compared, and the greater Roy's root which corresponds to the increasing values of the statistic indicating increasing contributions of the effects to the model in question. For the case under study, the Pillai trace is 0.623 value closer to 1, thus showing that the explanatory variable has a significant effect on the values of the response variables, which is the score obtained by the students, in addition the Wilks' Lambda index resulted in 0, 377, which the lower its value, the greater the disparity between the groups being compared, i.e., it makes a significant difference between the control group with the experimental group, and finally the greater Roy's root (1.654) which indicates increasing contributions of the effects to the experiment. See table Multivariate tests. As shown in Table 2.

In addition, we have the graph of marginal measures, which compares the average scores obtained in each test, both for the control group and for the experimental group, in which we can appreciate and ratify what the table of statistical indexes indicates; means and variances with their maximum and minimum scores. Here it is shown that the control and experimental group that started with similar averages in the pretest, in the experimental group is slightly higher than the control group, but in the post-test, the experimental group is observed to be much higher than the control group, which makes it clear that the hypothesis is confirmed.

Finally, when observing the ANOVA table, it is seen that for the pretest score there is no significant difference between means between the control group and the experimental group since $p = 0.541$, a value >0.05, so the researcher's hypothesis is rejected, which is evident, since the new teaching method has not yet been applied, However, at the post-test level, $p = 0.001$, a value much lower than 0.05, so the researcher's hypothesis is accepted that the students who receive the teaching with the Brown and Wilson methodology have higher achievements than the students of the control group who receive the teaching in the traditional way.

5. Conclusions

Undoubtedly, the teaching of computer programming has become an essential skill for today's society in constant technological evolution. Programming not only involves learning a new language, but also developing problem-solving skills, logical thinking and creativity. That's why programming is becoming an essential skill in every field, from data science to web development to artificial intelligence. One of the best ways to teach programming is through the use of hands-on examples and projects. Students learn best when they are involved in hands-on projects and applications, and this helps them understand how programming can be applied in real-world situations. In addition, projects also allow them to work in teams and collaborate on solutions, important skills for any career in technology.

It is worth remembering that the teaching of programming aims to develop computational thinking skills in children and young people, which has become an essential skill for today's digital society, as it involves problem-solving and logical thinking skills that are necessary for the development of innovative technologies and solutions. Computational thinking can also help people

TABLE 1 Inter-subject effects test.

Origen	Sum of squares	df	Root mean square	*F*	Sig.	Partial Eta squared	Non-centrality parameter	Observed power
Intersection	105,248.40	1	105,248.4	3,147.288	<0.001	0.972	3,147.288	1.000
Group	614.20	1	614.203	18.367	<0.001	0.171	18.367	0.989
Error	2,976.24	89	33.441					

Has been calculated using alpha = 0.05.

TABLE 2 Multivariate tests.

	Value	*F*	Df of hypothesis	Error de	Sig.	Partial Eta squared	Non-centrality parameter	Observed power
Pillai trace	0.623	147.2	1.000	89.000	<0.001	0.623	147.203	1.000
Wilks lambda	0.377	147.2	1.000	89.000	<0.001	0.623	147.203	1.000
Hotelling trace	1.654	147.2	1.000	89.000	<0.001	0.623	147.203	1.000
Roy's mayor root	1.654	147.2	1.000	89.000	<0.001	0.623	147.203	1.000

Each F-tests the effect of TEST. These tests are based on linearly independent pairwise comparisons between the estimated marginal measures.
Has been calculated using alpha = 0.05.

understand how technologies work and how they can use them to improve their daily lives. Countries that have implemented computational thinking in their educational programs have a competitive advantage in the digital age, as their citizens have advanced skills and knowledge in technology and programming. These countries can develop advanced technological solutions and be at the forefront of innovation, allowing them to be more competitive in the global marketplace. In addition, computational thinking can also have a positive impact on a country's economy and employment. Jobs in technology and programming are in high demand around the world, and companies are increasingly looking for employees with advanced programming and technology skills.

In the study that is the subject of this report, there was undoubtedly an improvement in the students' learning, which is ratified in the increase of the mean and average, but even more significant was that the experimental group that was dispersed in the results tended to become more uniform in their learning, as shown by the results of the post-test. There is a positive effect of greater camaraderie and collaboration, which explains the certain uniformity of the post-test results of the experimental group, which did not occur in the control group, where the dispersion of results increased significantly. In the following graph, the pretest of the control group (PRETEST-COTROL) corresponds to the first scheme, followed by the pretest of the experimental group (PRETEST-EXPERIMENTAL), and in third position is the post-test of the control group (POSTEST-CONTROL) in which the increase in dispersion can be seen, Finally, further to the right is the scheme of the experimental group (POSTEST-EXPERIMENTAL), in which a greater uniformity in the results is observed.

Table 3, which shows the indicators of the control and experimental groups, clearly shows that the experimental group achieved better results than the control group, which are more significant in terms of the minimum value observed in the post-test and the uniformity of achievements, which tend to level out, which means that all students learned, approaching the total achievement score, however, none managed to reach 100% of the test.

Undoubtedly, having experimented with the didactic principles of Brown and Wilson, the lack of didactic tools for teaching programming and the lack of instruments to measure the skills achieved by the students are discussed. This report intends to be a pioneer contribution in this matter, and as the culmination of a project that took 2 and a half years of work, in which works from all over the world were analyzed, from the most diverse countries, such as China, South Korea, Japan, several European countries, Brazil and Argentina, among others, which allowed placing computational thinking as an essential skill for the 21st century, and which is projected as one of the educational tasks with the greatest impact in this century that is beginning.

6. Projections and limitations of the study

6.1. Limitations

The limitations of the study are in the experimental part in which it would be convenient to include a larger sample and from several institutions, which could show in a reliable way the goodness of the didactic principles of Brown and Wilson for the teaching of computer programming. The research worked with one course as the experimental group and another course as the control group, and each course with different professors, which could already pose a possible bias in the application of the methodology. One way in which the Brown and Wilson methodology could be applied that would allow eliminating one of the teacher biases would be to have the same teacher teach classes in the experimental group and in the control group, which could be replicated with several pairs of courses as control and experimental with the same teacher.

The general objective was to determine the effects of applying the didactic principles of Brown and Wilson (2018) on the teaching—learning process of programming in Python

TABLE 3 Indicators and results.

Index / Group	Pretest control	Pretest experimental	Post-test control	Post-test experimental
Median	16.5	16	31	34
Average	17.02	17.80	27.62	34.22
Minimum	8	8	9	28
Maximum	27	39	39	42
Standard Deviation	4.98	7.19	9.10	3.90
Variance	28.80	51.7	82.81	15.21
Confidence interval (95%)	15.60–18.44	15.53–20.08	25.04–30.2	32.99–35.45

Source: Own elaboration.

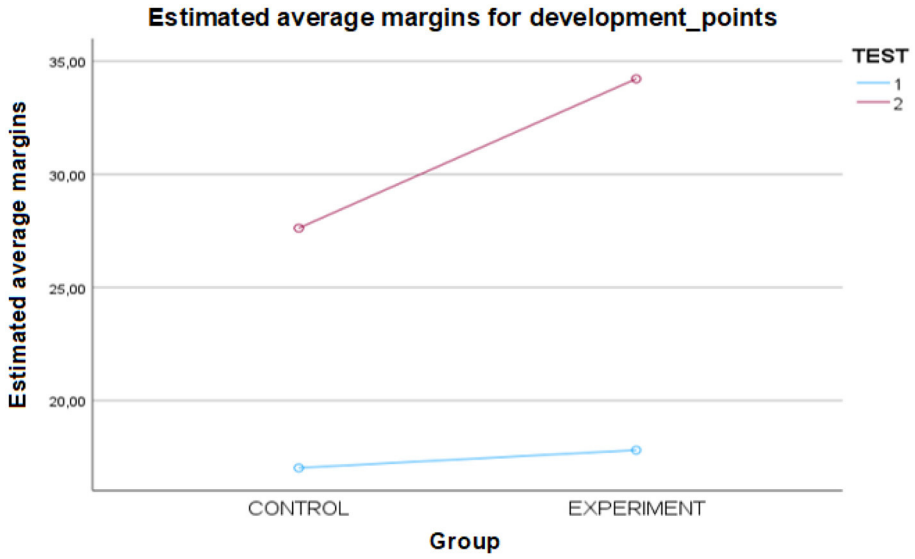

FIGURE 1
Estimated marginal averages by group.

with students of computer science careers of INACAP, an objective that is observed to be fully met, since the results were satisfactory, and project new scenarios to conduct new studies where the set of didactic principles of Brown and Wilson can be tested again (see Figure 1).

6.2. Projections

In the future there should be many investigations that test different didactic strategies for teaching programming. It should be noted that the didactics for primary and secondary students should be different from the one applied in tertiary education, since the latter works with adult students who have a specific purpose for which they carry out the study and not general as when they are in primary and secondary education. Thus emerges the concept of andragogy, which is the analog of pedagogy, but for adult education. Moreover, in the future it will not only be necessary to evaluate algorithms with conceptual or quantitative results, but it will be necessary to evaluate actions such as those performed by a robot or an automated machine (Carrillo, 2018).

The educational systems of the future, should incorporate not only the teaching of computational thinking, but also elements of neuroscience, so that once the basis of knowledge in computer programming, educational robotics and gamification is laid, it can go further, making the connection between computational processes and brain processes, in order to understand and create applications that are able to take advantage of brain waves in the activation of electronic devices that perform actions as an extension of the body, as there are already developments in the war industry, but with peaceful motivations and focused on the physical disabilities of human beings and also on brain disabilities in order to correct diseases such as deafness, blindness or go beyond, correcting Alzheimer's disease.

The teaching of computational thinking should permeate all knowledge formation in the educational system, integrating STEM

and non-STEM areas or better known as STEAM. Currently there are lost subjects such as technology education in Latin American countries when students are made to do crafts related to handicrafts or issues that contribute very little to the formation of knowledge. The subject of technology education should change its content from craft to technology, and should be composed of electronics, integrating electronic devices with the management of programs that allow students to be true generators of new digital technologies.

The formation of knowledge in schools should cut across all areas of knowledge, starting with mathematics and natural sciences, where one could experiment with the creation of virtual reality and/or augmented reality applications for chemistry and biology, passing through history and geography where one could teach through the creation of games and stories located in certain territories and eras, such as the Age of Empires game where different versions of the game show the ancient civilizations of Europe until about 1,700, and could create applications for schoolchildren on other continents, such as Africa, Latin America, Asia and Oceania. In language, tales and stories could be recreated to give life to letters, and in art, it could be integrated with virtual reality developments, so that students can navigate within technology, building the different educational knowledge, all of which would be done in a progressive and interactive way, training students in programming and gradually incorporating the skills of computational thinking.

Some of the computer science topics that could be studied and evaluated in the future would be computer security, computer programming in education, disconnected activities in learning computational thinking, didactic strategies in the teaching and learning process of programming, internet of things, data science and big data, artificial intelligence, students with special needs and studies on psychological aspects of technology and humans, in addition to deepening on gamification and educational robotics in primary school and robotics and industrial automation in secondary school, so that learning by projects, learning by doing, is practiced. It should be noted that all this should be properly distributed in the 12 years of primary and secondary education.

In addition to the above, there are emerging technologies such as nanotechnology and quantum computing, topics that should be part of the educational system in research phases and emerging technology topics. It should be noted that companies such as IBM already have prototypes of quantum computers that are fully operational. It is important to keep in mind that a quantum computer can decode all existing computer security systems in the world in just minutes, which will leave governments and organizations around the world unprotected. This happens because of the processing speed of this type of computers, since they are based on the parallelism of the binary system. While in the current electronic system, the bits (1 and 0) manifest themselves sequentially, in the quantum system they do so in parallel.

Finally, I would like to make a reflection on the difference in priorities between countries, which occurs on multiple levels; cultural, economic, technological, political and social, which leads us to think, where should we start from, should we promote the teaching of computational thinking as a way to transfer knowledge and thus in the medium and long term countries solve their social problems, or should we categorize where to start from, in addition to the fact that each country is independent. For example, in Haiti in Central America, with more than 200 years of independence, they still have not managed to have a stable political system that allows them to overcome extreme poverty and hunger. In this situation there are several countries in Africa and Latin America, while the world, represented by the developed countries, is faced with the dilemma of climate change, which is just around the corner and which will affect us all. I firmly believe that, in order of priority, the teaching of computational thinking is second only to climate change and world hunger.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by Institutional Ethics Committee - Universidad de Santiago de Chile. The patients/participants provided their written informed consent to participate in this study.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

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

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomp.2023.1085507/full#supplementary-material

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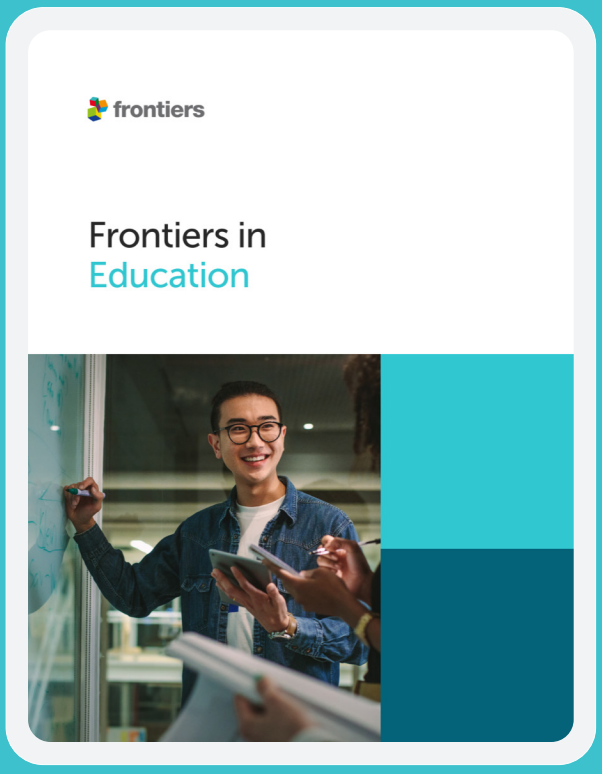

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