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Fostering digital transformation in education: technology enhanced learning from professors' experiences in emergency remote teaching

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In this work, we aim to understand professors' perception of the key competences as well as the best educational strategies and technological tools to guide digital transformation (DT) in education, according to their experience in emergency remote teaching (ERT). In recent years, technological advancement has driven DT in many areas, with education being among them. ERT due to COVID-19 accelerated this transition. Restrictions and lockdowns forced higher education institutions to adopt remote teaching strategies and tools suited for a digital environment. We surveyed 100 professors from a private Mexican university with 15-month experience of online ERT. We asked them through Likert scale questions to self-evaluate their performance and whether they perceived it to be better in online or hybrid environments compared with face-to-face environments in different aspects. We performed correlation, cluster, and factor analysis to identify the relationships and patterns in their answers. Through open-ended questions, we also asked the participants about the challenges and achievements they experienced, and the educational strategies and technological tools they successfully incorporated during ERT. We also conducted text mining to extract the most relevant information from these answers and validated that they were not polarized with negative sentiment using a large language model. Our results showed social intelligence as an underlying competence for teaching performance was highlighted in the digital environment due to the physical interaction limitations. Participants found success in implementing information and communication technologies, resulting in maintaining student interest and building trust in the online environment. Professors recognized the relevance not only of learning management systems and communication platforms, as expected, but also hardware such as tablets, cameras, and headphones for the successful delivery of education in a digital environment. Technology Enhanced Learning transposes game-based, quizzing practices, and collaborative learning to digital environments. Furthermore, the professors recommended learning-by-doing, flipped learning, problem-based learning, game-based learning, and holistic education as some pedagogical methodologies that were successfully applied in ERT and could be implemented for DT. Understanding the gains concerning teaching learning strategies and technologies that were incorporated during ERT is of the utmost importance for driving DT and its benefits for current and future education.

KEYWORDS

information and communication technologies, higher education, technology enhanced learning, educational innovation, digital transformation in education, faculty experiences, emergency remote teaching

1. Introduction

The advent of digital computing has triggered a digital transformation (DT) in every human sector (Zaoui and Souissi, 2020). DT refers to the integration of information and communication technologies (ICT) as well as computing and connectivity technologies into an organization (Vial, 2019; Itten et al., 2020).

DT has introduced new mechanisms for how organizations can succeed, grow, and stay competitive (Kraus et al., 2022) by integrating IT infrastructure and digital resources with the appropriate organizational strategies (Zhang et al., 2023). It is about redesigning how an organization uses technological and human resources as well as processes to fundamentally change its performance. It is an essential factor of Industry 4.0 and is revolutionizing how humans address problems in different fields (Kraus et al., 2021). The purpose is to improve efficiency and productivity, customer expectations, data-driven decision making, innovation, and resilience and adaptability. Furthermore, DT also involves changes in leadership, different thinking, innovation and new business models, and the incorporation of digitization in every aspect of the organization (Klein, 2020).

Higher education institutions (HEIs) have the main purpose of preparing students to become professionals and part of the future workforce (Khan et al., 2022). The contemporary technological landscape with its fast and continuous evolution demands professionals be equipped with digital and technological skills (Akour and Alenezi, 2022). That is why HEIs should aim for DT to keep evolving along with companies and industries, and to fill the current labor market needs (Benavides et al., 2020). This is achieved in two ways: by fostering the progressive process of digital infrastructure from a bottom-up direction, where subjects are gradually digitalized; and top-down processes, where strategic and logistical needs are served by larger and shared solutions (Bygstad et al., 2022). Despite much work being done regarding DT in the business field, further work needs to be done in the higher education field.

DT in HEIs is attained through different strategies, including digital strategies. HEIs must incorporate the use of technological tools in the classroom (Abelha et al., 2020), such as delivering courses via distance education tools that consist of online synchronous transmission supported by computer tools such as video communication platforms (García-Morales et al., 2021), and with other support tools, such as the use of AI to detect the sentiment of the students and in this way measure the effectiveness of the lecture (Giang et al., 2020). A digital strategy also supports an operational optimization strategy by improving students' experience through providing technology to faculties, training on teaching methodologies, and tools to deliver these methodologies (Fernández et al., 2023). Finally, a digital strategy also supports a technological optimization strategy by selecting the best video communication platforms and working with the provider to maximize security issues, educational features, and quality of delivery (Alenezi, 2023). The challenge of implementing these strategies is accompanied by the ability of faculties to adapt and use these tools in the best way. In this adaptation, faculties have to implement their own teaching strategies to be effective.

One of the largest leaps achieved toward DT in HEIs was forced by emergency and occurred during the COVID-19 pandemic. To stop the spread of the disease, governments around the world implemented lockdowns. All economic activities were affected, and they had to design and develop aggressive strategies to minimize the negative effects (Kumar et al., 2021). During this period, HEIs aimed to continue delivering high quality education and implemented several disruptive teaching and digital strategies. This is why the purpose of this work is to survey faculties to understand the challenges they faced and the strategies they found effective to deliver high quality courses while addressing DT. It was guided by the following research questions: (1) What teaching-learning strategies and technologies were successfully incorporated by teachers accustomed to face-to-face courses during remote education? and (2) What teaching-learning strategies and technologies do they recommend to other professors to effectively carry out online courses?

The current work will provide relevant information and insights on DT, supporting emergency remote teaching, to understand how DT can: ensure uninterrupted learning in the face of possible crises; increase access and equity to make education more accessible to students due to geographical, financial, or personal constraints; improve efficiency and innovation to achieve more efficient administrative processes and innovative teaching methods using digital tools; and ensure that graduates are fully equipped for the growing demand for digital skills.

2. Theoretical framework

Higher education institutions (HEIs) lead societal change and improvements. In this case, HEIs contribute to the digital development of the geographical regions where they operate. Teixeira and collaborators indicated that besides the acquisition of knowledge and skills, higher education contributes to job creation and to the improvement of the quality of life at work. They affirm that in recent years there has been a greater involvement between higher education and the labor market, namely, through research centers, business consultancy, and partnerships with local organizations (Teixeira et al., 2021).

DT inside HEIs goes beyond technological progress; it is a deep and transcendental evolution that generates changes in the mission, the philosophy, the pedagogical approaches, the teaching and learning processes, the research, the administrative activities, and even the relationships with other societal organizations. DT demands rethinking, restructuring, and reinventing HEIs from its multi-purpose, multi-processes, multidisciplinary, multistate, and

multi-stakeholders character. That is, DT should be an integral and holistic transformation of HEIs (Benavides et al., 2020).

From the educational dimension, DT involves integrating digital technologies into teaching, learning, and organizational practices as a resource to create additional and differentiated value for students and other stakeholders. DT is more than just digitizing information and processes; it is about leveraging technology to redesign educational processes, culture, and educational stakeholders' experiences to meet changing educational and labor market requirements (Benavides et al., 2020). Beyond students, the aim of DT is to benefit other educational stakeholders. These include: employers, parents, research funding agencies, and the community (clients); other universities and educational institutions, either local or international, formal, or informal, with physical or online campuses (competitors); and publishers, technology providers, faculty, staff, and other societal partners (providers).

The positive aspects of DT for administrative staff inside HEIs are manifested in improving information flow management, providing open access to educational resources and research results, and reducing the cost of higher education. Among the benefits of the DT of HEIs are ensuring a broader delivery of higher education through distance learning courses, thereby fostering its accessibility and mass scale, and making training and learning more flexible, personalized, and effective (Штыхно et al., 2020).

In this context, computer-supported collaborative learning (CSCL) is concerned with how information and communication technologies (ICTs) can support education (Ludvigsen and Mørch, 2010). The use of ICTs is an essential component for effective online teaching (Vikas and Mathur, 2022). New technologies have been used and applied to online learning, such as learning management systems (LMS), synchronization services, and social network tools (Bond et al., 2021).

Incorporating technology in education has been shown to have both negative and positive impacts throughout the years. On the one hand, it allows the non-academic use of technology which increases academic distraction (Dontre, 2021) and opens the possibility of academic dishonesty through cheating when searching for content on the internet (Golden and Kohlbeck, 2020), and excessive use of technology has been shown to be associated with lower academic performance (Gorjón and Osés, 2023). On the other hand, it enhances the learning experience (Dunn and Kennedy, 2019; Shen and Ho, 2020; Rosli and Saleh, 2022), improves accessibility (Coleman and Berge, 2018; Seale, 2020), fosters active learning (Theobald et al., 2020), promotes collaboration (Blau et al., 2020), and keeps pace with technological advancements (Miranda et al., 2021). Furthermore, it helps develop digital competence or digital literacy. This competence is defined as "the ability and disposition to use digital media, to develop them in a productive and creative way. It refers to the capacity to critically reflect on its usage and the impact media have on society and work, both for private and professional contexts, as well as the understanding of the potentials and limits of digital media and their effects" (Blau et al., 2020; Ehlers, 2021).

In response to students' expectations and the multiple benefits that DT provides, nowadays it is mandatory to foster DT inside HEIs. The use of ICT from a technological, informational, multimedia, communicative, collaborative, and ethical perspective is no longer optional for professors (Basilotta-Gómez-Pablos et al., 2022). They should strengthen their digital competence as an essential skill required for in the era of Industry 4.0 (Ehlers, 2021). Nevertheless, it has been discussed how educational institutions should provide training to teachers and professors in this matter to enable appropriate technology pedagogy integration, since current efforts are not enough (Bhebhe et al., 2023; Pozas and Letzel, 2023).

In this regard, the COVID-19 pandemic was an opportunity to attain DT in education (Mhlanga et al., 2022), the outcomes of which will not only be helpful in health contingencies but also during other emergencies such as natural disasters or wars, for instance, the current war in Ukraine (Banyoi et al., 2023). The COVID-19 outbreak accelerated DT in HEIs through the pervasion of ICTs into the classrooms. It forced a migration from face-to-face courses to online and hybrid learning in a short period of time, which represented a challenge for educational institutions (Daniel, 2020). Even though online learning was already present in some HEIs around the world, many universities had to focus on the redesign of courses by implementing new strategies and technologies (Zhang et al., 2022) leading to sudden emergency remote teaching (ERT) practices (Hodges et al., 2020).

ERT forced every educational stakeholder to adapt to new virtual environments. Students' behavioral, cognitive, and affective engagement has been shown to be a relevant factor for online learning (Daher et al., 2021; Salas-Pilco et al., 2022; Yang et al., 2022). During distance learning, students themselves have acknowledged that strategies not usually applied in face-to-face courses have been necessary, such as concerning about their well-being and implementing additional technological tools (Utomo et al., 2020; George and Thomas, 2021; Mondragon-Estrada and Camacho-Zuniga, 2021). Moreover, online pedagogy requires teachers with skills and capabilities for implementing technological tools and new strategies (Llerena-Izquierdo and Ayala-Carabajo, 2021; Archambault et al., 2022). Educational institutions should assist teachers and professors through ICT support staff as well as adequate end-user training to avoid negative consequences in their well-being (Pozo-Rico et al., 2020; Wang and Zhao, 2023). For instance, technostress, defined as an adaptation problem to cope or get used to ICTs, is an undesired consequence of new computer technologies (Ahmad et al., 2012).

Professors and teachers must foster DT in the educational ecosystem. It has been suggested that by pedagogically pre-designing their courses using modern pedagogical technologies and preparing their lectures using ICTs, teachers make students learn those technological tools as a means of teaching (Olimov and Mamurova, 2022). This involves not only using some technological tools for some activities but also embracing a more flexible approach that could open new possibilities in the classroom (Feerick et al., 2022).

New technologies such as the metaverse (Misirlis and Munawar, 2023) and AI models such as ChatGPT (Mhlanga, 2023) have been proposed to be applied in education to further advance DT in HEIs. However, the fact remains that every time there are new technologies to be used requires teachers and professors to be properly prepared. Our study examines the opinions of professors that experienced ERT during COVID-19 lockdown and who advise educational strategies and technological tools that were, in their perspective, suitable for this challenge and those that will inevitably continue to exist in the growing technological age.

3. Materials and methods

3.1. Participants

In total, 100 faculty members from a private university in Mexico with experience teaching online courses for 15 months due to the

COVID-19 outbreak participated in this study voluntarily. They were informed about the research purpose of the survey and agreed to the anonymous and confidential use of their provided information.

From this sample, ($n = 44$) were female, ($n = 52$) male, and ($n = 4$] unspecified. The professors belonged to different schools inside the university: ($n = 22$) were from the School of Engineering, ($n = 22$) from the School of Sciences, ($n = 19$) from the School of Social Sciences, ($n = 18$) from the School of Arts and Humanities, ($n = 18$) from the School of Business and Economics, and (n = 1) form the School of Research and Graduates. Their teaching experience was between 2 and 48 years (mean = 17.8 years, SD = 11.7 years).

3.2. Data collection

An online optional survey was disseminated among 289 full-time professors of a private university in Mexico via institutional email, from which 100 answered. The survey consisted of seven sections, the first one regarding sociodemographic information and the remaining six sections are explained below.

Section 1 consisted of seven Likert scale items (1 – Poor, 5 – Excellent) about the participants' perceptions of their performance during online or hybrid courses in different aspects: (1) motivation, trust, empathy, and ethical commitment (Empathy); (2) methodological teaching strategies (Methodol.); (3) use of information and communications technology (ICT); (4) communication with students (Comm.); (5) course content design (Design); (6) collaboration with other faculty members (Collab.); and (7) creating and applying new methodologies, resources, and knowledge (Innov.). We included these aspects inspired by the previously published literature on the competences that a professor or university teacher should possess (Perez-Poch and López, 2016) and added the use of ICT as a fundamental skill for the digital transformation of teaching.

Section 2 included seven items about whether the participants perceived their performance to be better in online and hybrid environments compared with face-to-face environments. They analyzed the same aspects evaluated in Section 1 as Likert scale questions (1 – The face-to-face model is much better, 5 – The hybrid or online model is much better).

Sections 3 and 4 corresponded to open-ended questions asking participants about their biggest challenges and achievements, respectively, as professors during online or hybrid courses. Finally, Sections 5 and 6 consisted of open-ended questions seeking participants' recommendations for educational strategies and technologies, respectively, to improve their teaching based on their experiences in online and hybrid courses.

3.3. Data processing and analysis

3.3.1. Investigating the relationships between competences

To find how aspects (Empathy, Methodol., ICT, Comm, Design, and Collab. Innov) related to each other, we performed correlation, cluster, and factor analysis for the Likert scale questions in Sections 1 and 2 using R (R Core Team, 2022). To find the extent to which the categorical variables moved in the same or opposite direction consistently, correlation matrices were computed using the non-parametric Spearman's rank correlation coefficient along with their significance levels for each section. Since we were interested in knowing how similar these aspects are to each other and how they could be grouped, we performed hierarchical clustering via complete-linkage clustering using Gower's distance, a metric suitable for categorical data (Maechler, 2022). Factor loadings were found by performing maximum-likelihood factor analysis with different numbers of factors (one, two, or three) to be fitted for each section to find unobserved latent variables that explained the variability of the collected data. For the factor analysis, we assumed our sample size was large enough, so that the sampling distribution of the mean of any independent, random variable would be normal or nearly normal, according to the central limit theorem.

3.3.2. Faculty's strengths and weaknesses

For obtaining insights regarding professors' main challenges and achievements during online or hybrid courses, we were required to perform natural language text analysis on the responses to the open-ended questions of Section 3 and 4. This text analysis can be done through term frequency (TF) and term frequency – inverse document frequency (TF-IDF). TF-IDF is a statistical measure that evaluates how relevant a word is to a document in a collection of documents. Thus, TF-IDF was computed to extract key terms from faculty members' answers. It was calculated as follows (Silge and Robinson, 2016):

$$\text{TF-IDF}(t,q,Q) = \frac{f_q(t)}{\max_{w \in q} f_q(w)} \cdot \ln\left(\frac{|Q|}{|\{q \in Q : t \in q\}|}\right) \quad (1)$$

where $f_q(t)$ is the frequency of the term t in the answer to question q, w is the number of words in the answer to question q, and Q is the total number of questions.

3.3.3. Validating faculty members' polarity

Text sentiment analysis can be used to determine the sentiment and polarity of answers to challenges and achievements (Sections 3 and 4). Polarity depends on the balance of *objective fact statements* and *subjective non-fact statements* (Sahu and Majumdar, 2017). Facts are objective terms like events, entities, and their properties. On the other hand, a non-fact statement is subjective and usually related to an individual's sentiments, personal beliefs, opinion, perspective, feelings, or thoughts. Therefore, we performed sentiment analysis to confirm the objectivity of the faculty members' answers to the survey.

For this analysis, we used large language models (LLMs) because in the last few years these models have been shown to outperform classical data-driven models, such as Support Vector Machines (SVMs) and Recurrent Neural Networks (RNNs) for natural language processing (NLP) tasks (Fan et al., 2023). There are many LLMs but we used the RoBERTuito (Pérez et al., 2021a,b) as our LLM, because it has been shown to outperform other state-of-the-art LLMs, such as RoBERTa, for sentimental analysis in Spanish.

3.3.4. Educational strategies and technological tools analysis

We were interested to know which educational strategies and technological tools were recommended to be applied before a lecture, during a lecture, and after a lecture. Therefore, for educational strategies, we carefully analyzed all answers and created a tree

structure to have a visual plot. We were also interested to know what type of technology is effective; therefore, we carefully analyzed all the faculty members' answers and created a matrix relating specific technology with categories. Additionally, we performed TF-IDF as described in Eq. 1 to contrast both results.

4. Results

4.1. Investigating the relationships between competences

Professors' performance involves multiple competences (Perez-Poch and López, 2016); Teaching is a complex activity where every factor that was analyzed in this work benefits the rest. Professors' self-evaluation (1 – Poor, 5 – Excellent) had a median value of 4 ($IQR = 1$) for the seven aspects. Figure 1 depicts the heat map of the correlation matrix using Spearman's rank for the seven aspects that professors perceived about their own performance (dark blue = 1 and white = 0); the dendrogram resulting from hierarchical clustering is also shown. Every correlation is positive and significant ($p < 0.05$), reflecting that professors' performance involves every aspect evaluated in Section 1, and that each one of them contributes to the rest in a positively related manner.

In the current technology-driven educational environment, professors recognized the relevance of innovation, that is, creating and applying new methodologies, resources, and knowledge, into teaching methodology and course content design. Correlation analysis showed that, according to faculty members' perceptions of their own performance, the highest coefficients corresponded to methodology and innovation [$r(98) = 0.617$] together with innovation and course design [$r(98) = 0.553$]. This also highlights a unique opportunity for HEIs to improve, since in previous studies innovation was identified as inherent to online educational models (Camacho-Zuñiga et al., 2023).

In current research, collaborative work among faculty members showed little correlation with professors' own evaluation of their performance. The dendrogram from Figure 1 shows three relevant clusters:

- Innovation, methodology, and design: these concern the characteristics of the course;
- Communication, empathy, and ICTs: these pertain to the human interactions involved in the teaching and learning process and the means of communication; and
- Collaboration with other faculty members: this aspect was not merged into any other cluster and showed the lowest correlation with the other aspects.

Innovation can be understood as the combination of the four Cs of the 21st century skills: critical thinking, collaboration, creativity, and communication (Demirkol-Orak and İnözü, 2021). The fact that innovation was accompanied by methodology and design evidences

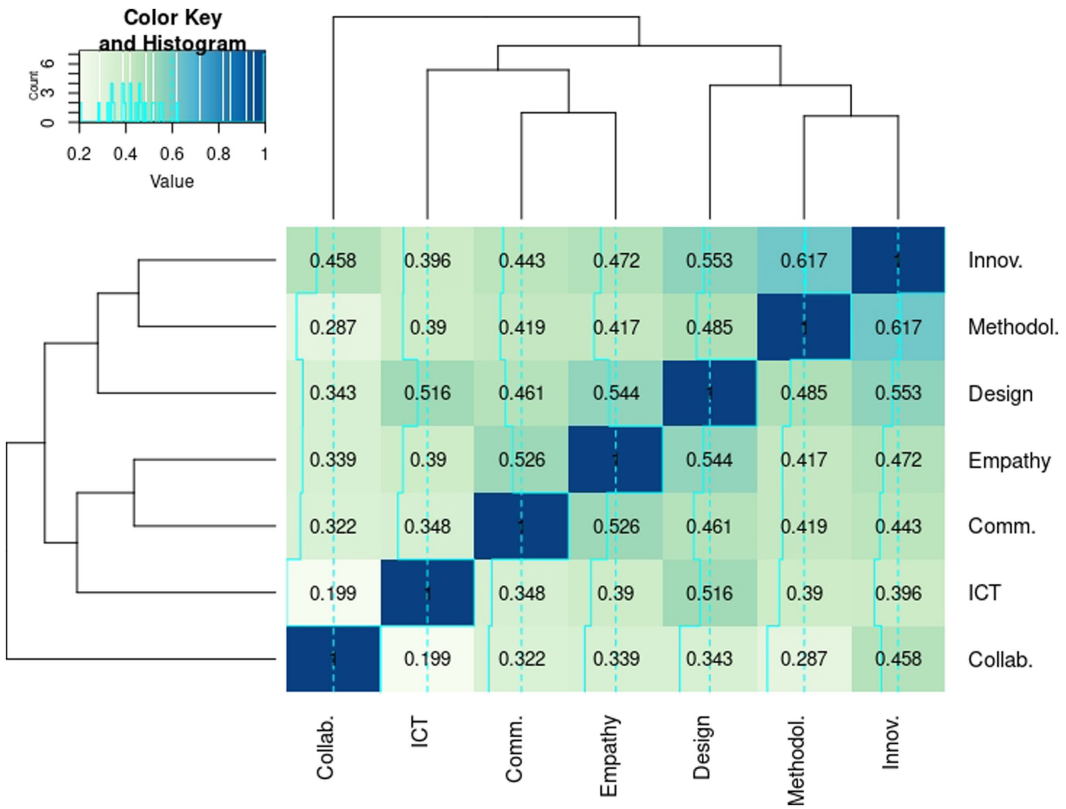

FIGURE 1
Heat map representation of the correlation matrix (Spearman's rank) for the seven aspects that professors perceived about their own performance in online education along with its dendrogram resulting from hierarchical clustering (every coefficient fulfilled $p < 0.05$).

the importance of creativity and critical thinking applied to the course content design, which is in accordance with previous work (Demirkol-Orak and İnözü, 2021).

Collaborative work among faculty members has been reported to trigger professors' performance improvement (De Oca et al., 2021); in agreement, the current research revealed a positive correlation between innovation and faculty collaboration. Previous work (Garzón Artacho et al., 2020) has shown that use of ICTs has a direct relationship with communication, collaboration, and content creation. Similarly, in our analysis, communication and empathy were clustered with the use of ICTs, but collaboration was not clustered with the use of ICTs, but, in the opposite way, collaboration was clustered apart.

In Section 2, regarding the same seven aspects as in Section 1, professors expressed their opinion about the best teaching model in a Likert scale, where 1 represented face-to-face model, and 5 hybrid or online model. Face-to-face model was better at Empathy, with 32% of professors selecting 1. As could be expected, hybrid or online model was better at ICT, with 33% of professors selecting 4. Methodology, Communication, Design, Collaboration, and Innovation were equally evaluated in both models, with 28%-46% of professors selecting 3 for these aspects. Figure 2 displays a heat map corresponding to the Spearman's rank correlation coefficients of the professors' responses to Section 2 as well as the dendrogram from hierarchical clustering. All correlations are positive and significant ($p < 0.05$). The pairs with the highest correlation coefficients were course design–methodology, teaching methodology–innovation, and course design–innovation. The three aspects are similar and were grouped in the same cluster, echoing the findings from Section 1 (see Figure 1). Moreover, communication and empathy are similar, and they, in turn, exhibited a similarity with both faculty collaboration and the use of ICTs.

The hierarchical clusterings reported in Figures 1, 2 suggest that the use of ICT in education either demands for strong faculty collaboration or that such collaboration facilitates the incorporation of ICTs and the ongoing innovation of online or hybrid learning.

Evaluations of teachers' performance usually consider teaching methodology and course content (Abbas et al., 2022); however, the current work evidences that the shift from face-to-face to online teaching highlighted social intelligence as a fundamental competence for professors' performance. Factor analysis was performed using one, two, and three factors along with a chi-square test (H0: n number of factors are sufficient to explain the set of observations). For faculty members' perceptions of their performance (Section 1), three factors were sufficient to explain the set of observations [$\chi^2(3, N = 100) = 0.74$, $p = 0.863$] Table 1 reports the loadings of those factors and the interpretation from the authors' point of view:

1. "Innovative teaching methodology": innovation (0.921), methodology (0.470), and faculty collaboration (0.390) have the highest loading values in this factor. The first two are related

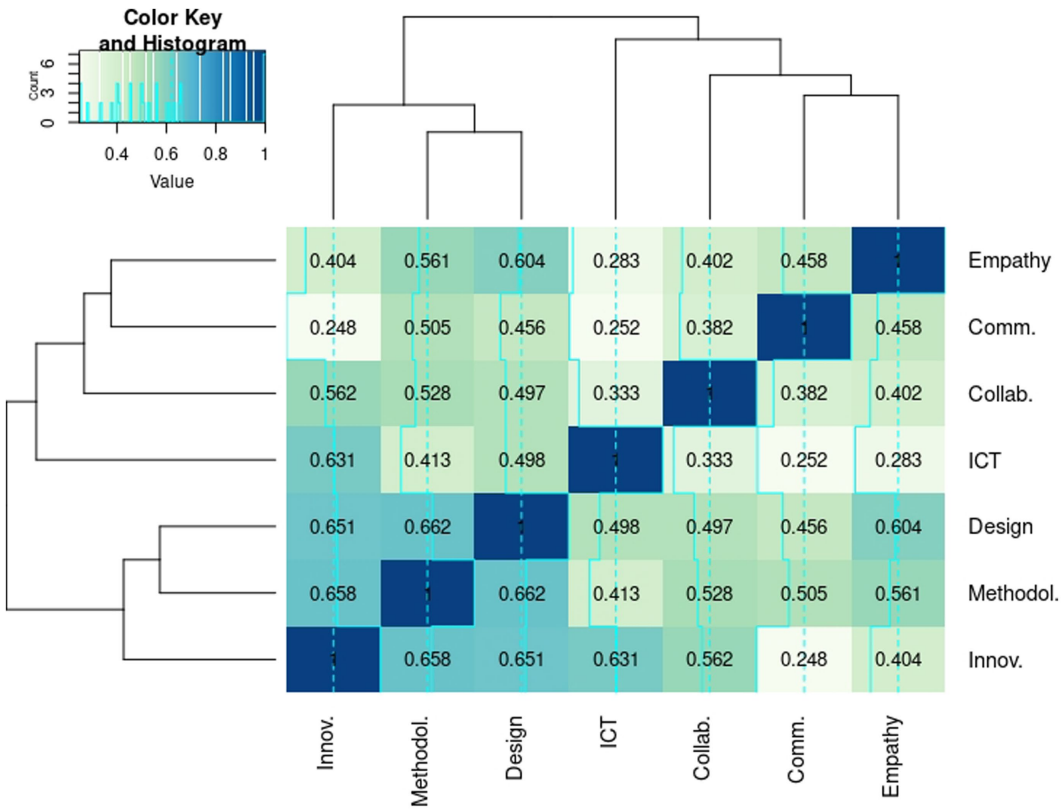

FIGURE 2
Heat map representation of the correlation matrix (Spearman's rank) and dendrogram resulting from hierarchical clustering for the seven aspects that professors ranked to be better between hybrid or online models and face-to-face models (every coefficient fulfilled $p < 0.05$).

TABLE 1 Loadings found for faculty members' perceptions of their own performance (Section 1 of the survey) during online education using factor analysis with three factors.

Category	Factor 1 "Innovative teaching methodology"	Factor 2 "Instructional design"	Factor 3 "Social intelligence and communication"
Empathy	0.242	0.373	0.592
Methodology	0.470	0.384	0.274
ICT	0.178	0.499	0.275
Communication	0.219	0.298	0.553
Design	0.288	0.702	0.273
Collaboration	0.390	0.108	0.319
Innovation	0.921	0.323	0.206

TABLE 2 Loadings found for faculty members' comparison of face-to-face vs. online education (Section 2 of the survey) during online education using factor analysis with three factors.

Category	Factor 1 "Technology-driven teaching methodology"	Factor 2 "Social intelligence and communication"	Factor 3 "Instructional design"
Empathy	0.240	0.598	0.315
Methodology	0.519	0.639	0.182
ICT	0.589	0.182	0.251
Communication	0.113	0.662	0.135
Design	0.456	0.455	0.762
Collaboration	0.496	0.418	0.161
Innovation	0.959	0.200	0.190

with creating and applying new resources, knowledge, and teaching methodologies, and the third pertains to collaboration with other faculty members to include ICTs and improving the teaching methodology.

2. "Instructional design": in this factor, design (0.702) holds the highest loading, followed by ICT (0.499) and empathy (0.373). Overall, it might suggest that empathizing with the student while designing the course material using ICTs is an underlying feature of course design.
3. "Social intelligence and communication": in this factor, empathy (0.592), communication (0.553), and faculty collaboration (0.319) have the highest loadings. All three pertain to human interactions, which might be an apt description of this latent variable.

For this research, we consider social intelligence as being able to generate effective environments for collaboration and negotiation in multicultural contexts with respect and appreciation for the diversity of people, knowledge, and cultures. Communication refers to effectively using different languages, resources, and strategies according to the context for an effective interaction within various professional and personal networks with different purposes or objectives (Instituto Tecnológico y de Estudios Superiores de Monterrey, 2018; Ehlers, 2021). Perez-Poch and López previously reported that working collaboratively with the rest of the faculty was perceived by professors as the least important teaching competence (Perez-Poch and López, 2016). In contrast, our evidence shows that this competence as a part of social intelligence is fundamental in both face-to-face and digital supported interactions. Moreover, social intelligence and communication are valuable for interacting in heterogeneous groups in many areas of life through cooperation, participation, and motivation, which has been shown to be greatly beneficial for education for sustainable development, as one of the 17 sustainable development goals adopted by the United Nations (Scherak and Rieckmann, 2020).

Online education contrasts to face-to-face education by being technology-driven and highly innovative. Faculty perceptions of whether online and hybrid courses or face-to-face courses are better in several aspects were reduced to three factors [$\chi^2(3, N = 100) = 3.97, p = 0.265$]. Table 2 reports the loadings for each factor:

1. "Technology-driven teaching methodology": innovation (0.959), use of ICTs (0.589), and methodology (0.519) were the variables with highest loadings in this factor. These are closely tied to educational strategies and technology, suggesting that the application of new methodologies using ICTs is a key factor in educational transformation.
2. "Social intelligence and communication": this factor reflects the relevance of social intelligence competences in teaching performance, as the concepts with the highest loadings were communication (0.662), methodology (0.639), and empathy (0.598).
3. "Instructional design": in this factor, design surpassed the rest of the aspects (0.762), followed by empathy (0.315). It can be inferred that professors should consider fostering student motivation, trust, empathy, and ethical commitment while designing a course.

TABLE 3 Top terms with highest TF-IDF values for professors' greatest challenges during online education.

Term	*N*	TF	IDF	TF-IDF
Challenge (*reto*)	6	0.004	1.386	0.006
Capture (*captar*)	8	0.005	0.693	0.004
Really (*realmente*)	4	0.002	1.386	0.004
Attention (*atención*)	15	0.010	0.287	0.003
Sound (*sonido*)	3	0.002	1.386	0.003
Can (*poder*)	5	0.004	0.693	0.003
Feedback (*retroalimentación*)	5	0.004	0.693	0.003
Student (*estudiante*)	4	0.003	0.693	0.002
Interaction (*interacción*)	4	0.003	0.693	0.002

TABLE 4 Top terms with highest TF-IDF values for professors' greatest achievements during online remote education.

Term	*N*	TF	IDF	TF-IDF
Despite (*a pesar*)	8	0.006	1.386	0.008
New (*nuevas*)	8	0.006	0.693	0.004
Situation (*situación*)	4	0.003	1.386	0.004
Model (*modelo*)	6	0.004	0.693	0.003
Trust (*confianza*)	3	0.002	1.386	0.003
ITCs (*TICs*)	3	0.002	1.386	0.003
Achieve (*lograr*)	14	0.010	0.287	0.003
Distance (*distancia*)	5	0.004	0.693	0.002
Interest (*interés*)	10	0.007	0.287	0.002

The words "which," "day," and "what" were removed from the list since they do not provide additional information.

4.2. Faculty members' strengths and weaknesses

Professors' main challenges (Section 3) during online or hybrid courses were keeping students' attention and engagement, maintaining student–student and student–professor interactions, and providing truly efficient feedback. TF-IDF was performed on the text responses regarding professors' biggest challenges and the main results are reported in Table 3. As expected, "challenge" (0.006) and "student" were among the terms with highest TF-IDF values. Other relevant terms were "capture" (0.005), "attention" (0.003), "feedback" (0.003), and "interaction" (0.002). In agreement with Camacho-Zuñiga et al. (2023), it can be inferred that capturing students' attention, providing truly efficient feedback, and, in general, lecturing without the usual immediate and physical bidirectional communication of a face-to-face course were significant challenges for the professors.

Professors found success in implementing ICTs and redesigning their methodologies for the new teaching model, resulting in maintaining student interest and building trust in the online environment, despite the challenging situation imposed by the COVID-19 lockdown. The terms with the highest TF-IDF values for professors' biggest achievements are revealed in Table 4. The presence of "despite", "new", "situation", and "distance" are understandable as means to describe the challenging environment for teaching. Other terms in this chart are "trust", "new", "model", and "ICTs", the last two with the highest TF-IDF values. The term 'trust' could refer to building trust with students in the online environment or gaining confidence in using digital tools; its relatively high IDF score indicates this was a significant achievement, but not as common. The presence of "ICTs" suggests professors made significant strides in implementing and using technology in their teaching which could also benefit the ability of the professors to maintain or stimulate the interest of the students in online education.

4.3. Validating faculty members' polarity

Sentiment analysis of the respondents' answers to their *biggest challenge* and their *greatest achievement* while shifting to online learning was mostly neutral, which might be evidence of the objectivity of their answers. Sentiment analysis categorizes each answer to be positive, neutral, and negative; The sum of the predicted probabilities for each category is one. Sentiment analysis for faculty members' answers to their *biggest challenges* resulted in 31 positive, 53 neutral, and 16 negative answers. Below, we report some examples of positive, neutral, and negative classified answers as well as their sentiment score. It is noteworthy that most of the negative classified answers related to the fact that professors and students were not sharing the same physical space and, therefore, professors were unable to get immediate feedback from students' reactions.

> *"I've actually gotten along well." (En realidad me he acoplado bien.) Sentiment score predicted: Positive: 0.780, Neutral: 0.201, Negative: 0.019.*

> *"Only the initial adaptation period. Most of the content was already prepared in digital format." (Solo el periodo de adaptacion inicial. La mayoria de los contenidos ya los tenía preparados en formato digital.) Neutral: 0.906, Positive: 0.052, Negative: 0.042.*

> *"Technical failures and not being able to see students during the session; thus, it has been very difficult to have non-verbal feedback of what is discussed." (Las fallas técnicas y el no poder ver a los estudiantes durante la sesión; así ha sido muy difícil tener una retroalimentación no verbal de lo que se discute.) Negative: 0.980, Neutral: 0.018, Positive: 0.002.*

Whereas the output for faculty members' answers to their *greatest achievements* were 46 positive, 52 neutral, and 1 negative. This shows that most of the answers were not polarized for negative sentiment. Examples of positive, neutral, and negative classified answers (and their sentiment scores) for this question are:

> *"Show to students that despite the limitations of the pandemic, interesting and high-quality projects can be carried out." (Demostrar a los estudiantes que a pesar de las limitantes propias de la pandemia se pueden hacer proyectos interesantes y de calidad.) Sentiment score predicted: Positive: 0.865, Neutral: 0.116, Negative: 0.019.*

> *"Definitely the use of ICTs (platforms such as Blackboard, Teams, etc.)." (Definitivamente el uso de las TICs (plataformas como Blackboard, Teams, etc).) Neutral: 0.829, Positive: 0.109, Negative: 0.062*

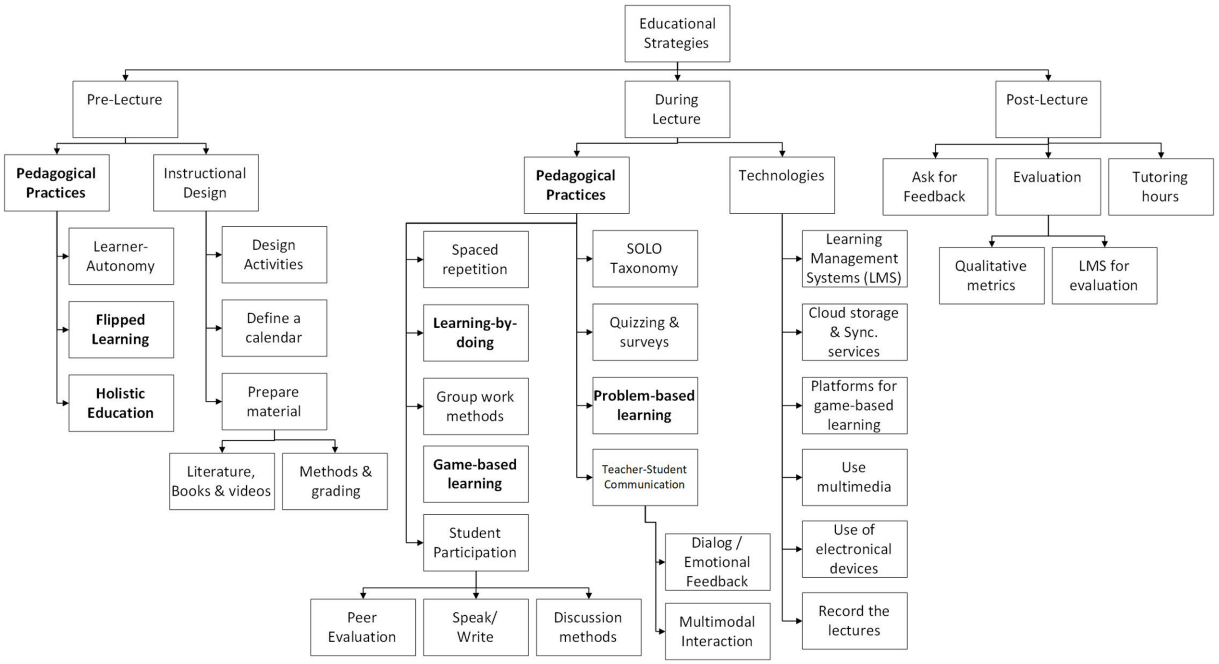

FIGURE 3
Educational strategies recommended by professors for DT of HEIs, categorized as pre-lecture, during a lecture, and post-lecture.

> *"Provide a critical and participatory space in which students do not lose interest despite how complex and tiring it is for them to spend so many hours in front of the screen in their individual spaces." (Generar un espacio crítico y participativo en el que los estudiantes no pierdan el interés a pesar de lo complejo y pesado que es para elles estar tantas horas frente a la pantalla en sus espacios individuales.) Negative: 0.692, Neutral: 0.261, Positive: 0.047*

Overall, most professors highlighted the use of ICTs as their greatest achievement, as well as the fact that they captured students' attention through innovative activities and by using technological tools.

4.4. Educational strategies and technological tools analysis

Multiple educational strategies were recommended by professors for an online or hybrid course (Section 5); however, the implementation of activities promoting interaction, collaborative learning, and learner autonomy were highlighted. Strategies were divided into three categories based on the time they could be applied: before a lecture, during a lecture, and after a lecture. Furthermore, during-lecture recommendations were divided into pedagogical and technological (see Figure 3).

During the lecture, technologies recommended comprise learning management systems (LMS) for organizing the content and grading works, cloud storage and synchronization services for collaborative activities, game-based learning platforms for interactive learning, use of multimedia such as videos and pictures, use of electronic devices, and recording the lectures for future reference. Professors also recommended the implementation of spaced repetition, learning-by-doing, and group work methods, as well as enhancing students' participation during the lecture through the technologies previously mentioned.

Strategies recommended before a lecture are related to the design of the course material, calendar, and activities. Learner autonomy, flipped learning, and holistic education are some pedagogical methodologies that were recommended by faculty members and that could be applied during the design of a course. On the other hand, after-lecture recommendations included grading and evaluation systems, providing tutoring hours, and asking the students for feedback on how they are understanding the topics.

Some of the key terms resulting from TF-IDF analysis of the professors' recommendations concerning educational methodologies were "content" (0.003), "collaborative" (0.002), "teams" (0.002), "course" (0.002), "flipped" (0.002), and "interactive" (0.002). These highlight the importance of the course content and working in teams. Also, the term 'flipped' appeared, pointing out the instructional strategy of flipped learning.

According to respondents' recommendations, the pedagogical strategies most successfully implemented in the online environment and that, therefore, could enhance DT in HEIs are:

- Learning-by-doing: a principle that states how people learn from experiences and actions, rather than by observing or listening to the instructor (Reese, 2011). This practical experience helps students to apply their knowledge easily to real life situations (Bradberry and De Maio, 2019). Furthermore, it has been shown that learning-by-doing plays a key role in digital literacy since students learn how to use technology by using it (Tan and Kim, 2015).
- Problem-based learning: this is a pedagogical approach that enables students to learn while engaging actively with meaningful problems (Yew and Goh, 2016). The process starts with a case or problem statement which students, through a systematic

approach, work on addressing. Electronic environments provide an ideal environment to enhance problem-based learning through lab simulators, video presentations, and graphic tools (Moust et al., 2021).

- Game-based learning: an educational approach for engaging appropriate cognitive processes by playing games, participating in game-related communities, or by using worked examples in the games (Tobias et al., 2014). Game-based learning has evolved over the years, from digital games, online applications, and videos to emerging technologies such as virtual and augmented reality (Yu et al., 2022).
- Flipped learning: this is a teaching approach in which the conventional notion of classroom-based learning is inverted. Students are introduced to the learning material before class and problem-solving activities along with discussion with peers is carried out in the classroom (El Miedany, 2019). Additionally, flipped learning has been empowered by the use of ICTs, which encourages autonomous work, motivates students, helps the analysis of the content, and facilitates the communication between students and teachers (Cueva and Inga, 2022).
- Holistic education: this refers to the educational vision that cares for the human being as a whole, which encapsulates balance, inclusion, and connectedness as principles (Miller, 2019). Since it relates to people's mindset directly, it can be greatly beneficial to enhance personal and social transformation to tackle current world problems (Miseliunaite et al., 2022).

Concerning technological implementations for online education, in agreement with previous literature, the professors recognized the relevance of LMS and communication platforms; even more, current research demonstrates that hardware, like Wacom tablets, digital pencils (Peimani and Kamalipour, 2021), microphones, headphones, and lightning accessories (Serianni and Coy, 2014), are highly recommended for online teaching. Professors' recommendations regarding technological tools for online or hybrid teaching were extracted from the text answers of Section 6. They were classified into different categories based on the nature or use of the tool (see Table 5). The first two categories are keys for online courses: LMS and communication platforms provide tools for managing course content and students' grades, as well as provide means of communication between professors and students. Furthermore, hardware was the third most repeated category, which is evidently necessary for efficient online teaching, including cameras, tablets, Wacom tablets, smartphones, and earphones. It is also noteworthy the relevance of cloud storage and synchronization systems, like Google Sites, that enable and promote collaborative learning.

Our results evidence that TEL spreads game-based and quizzing practices to online environments. Although quizzing and game-based learning are usual strategies in a face-to-face classroom, the participants recommended game-based platforms and Q&A/polling platforms—such as Kahoot!, Nearpod, Quizizz, Quizlet, Mentimeter, and Tweedback—as tools for engaging students during the online class. This agrees with other studies reporting that game-based learning fosters learning motivation in students (Wati and Yuniawatika, 2020; Sonsona et al., 2021; Krouska et al., 2022).

The biggest challenges reported during ERT were related to experimental activities and the strengthening of motor skills inside STEM (Science, Technology, Engineering, and Mathematics) laboratories, which in the digital world were addressed through the use of mathematical software and simulators. For Section 6, TF-IDF was also computed. Some of the terms with the highest TF-IDF values were technological tools such as (Microsoft) Teams (0.007), YouTube (0.003), Padlet (0.003), and Google (0.003). Interesting concepts such as "platform" (0.005), "videos" (0.005), and "simulators" (0.004) also appeared. Simulators are related to engineering courses like biology, chemistry, mechanics, and electronics. This agrees with previous literature where professors have used simulators for their STEM and clinical courses (Tabatabai, 2020; Mamani et al., 2021; Pradhan and Madihally, 2022).

The current study has contributed to understanding the pedagogical practices and technologies that drive digital transformation successfully. This is not just beneficial but essential for HEIs; however, we must recognize some limitations concerning this research. It was conducted in a private Mexican university, which might not be fully representative of other HEIs due to the digital gap that characterizes the Latin America region (Galperin and UNESCO Office Montevideo and Regional Bureau for Science in Latin America and the Caribbean, 2017). Furthermore, this study was conceived during the COVID-19 pandemic, long before the release of ChatGPT into the public domain. Since then, a lot of AI tools have gained popularity and will impact higher education and its DT. These technologies could be addressed in a future study.

5. Conclusion

Advances in technology are fast paced, faster than our ability to incorporate its benefits into education; COVID-19 lockdown helped us to accelerate digital transition, but we are still far from Digital Transformation (DT) and its benefits. That is why knowing which teaching-learning strategies and technologies have been successfully incorporated by professors during Emergency Remote Teaching (ERT) is of the utmost importance for extrapolating them to current and future education.

This work collected the perceptions and recommendations of teaching-learning strategies and educational tools from 100 faculty members from a private university in Mexico, with an average teaching experience of 17.8 years and who had been delivering online courses for 15 months due to COVID-19 lockdowns. Our findings show that under the current technology-driven educational environment and toward a DT of higher education institutions (HEIs):

1. Innovation is a fundamental feature for better course content design, that is, creating and applying new methodologies.
2. Social intelligence and communication are underlying competences for professors' performance that were highlighted in the digital environment due to interaction limitations in this context.
3. The pedagogies considered to be most conducive for DT are learning-by-doing, problem-based learning, game-based learning, flipped learning, and holistic education. Professors successfully applied them in ERT and, furthermore, they could be implemented in online, face-to-face, or hybrid courses.
4. Professors found success in implementing information and communication technologies (ICTs) and redesigning their methodologies for the new teaching model, resulting in

TABLE 5 Technological tools recommended by participants for the DT of HEIs, and carefully classified by the authors in different categories based on the nature or use of the tool.

Technological Tool	Learning management system (LMS)	Communication platform /instant messaging	Hardware	Cloud storage / synchronization service	Presentation software	Game-based learning platform	Software for mathematics and simulation	Q&A / polling platform	Virtual white board	Videoconferencing tool	Online video platforms (OVP) / streaming	Screen casting	Note-taking software	Quiz platform	Online social annotation platform
Frequency	37	15	12	11	6	6	6	5	5	3	3	3	2	1	1
Blackboard	x	x		x										x	
Canvas	x	x		x										x	
Zoom		x						x	x	x	x	x			x
Teams		x		x				x		x	x	x		x	
Microsoft whiteboard				x					x				x		x
Microsoft office suite		x		x	x								x		
Google sites		x		x	x			x					x	x	
Miro				x	x								x		
Padlet				x	x								x		
Mentimeter				x	x			x							x
Genially				x	x										
Tweedback								x							x
Awingu, VPN software															
Idroo		x		x	x				x				x		
Blogger															
Monkey survey				x				x						x	
Kahoot!						x		x						x	
Nearpod					x	x		x						x	x
Quizizz						x								x	
Quizlet						x								x	x
Perusall								x							x
Slido		x			x			x							x
Backchannel chat		x						x							x
Mural				x					x				x		
YouTube										x	x				
OBS studio											x	x			
Mathematica							x								
GeoGebra							x								
Camera			x												
Wacom and other tablets			x												
Monitors			x												
Phones and smartphones			x												
Earphones			x												

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maintaining student interest and building trust in the online environment.

5. Professors recognized the relevance not only of learning management systems (LMS) and communication platforms, as could be expected, but also hardware such as camera, earphones, and Wacom and other tablets that facilitate the successful delivery of a digital lecture.
6. Technology Enhanced Learning (TEL) spreads game-based, quizzing practices, and collaborative learning to the online environments, while simulators cover those course contents that used to take place in STEM laboratories.

Our research evidences the importance of incorporating TEL and ICTs in education from the classroom to advance the DT of HEIs. To fulfill the current industry requirements, it is important that these practices not only remain in a remote education context but also become an essential part in present and future education. Technology and science evolve rapidly, and it is the duty of professors and HEIs to prepare students, the next decision-makers, to be properly equipped to address the challenges and opportunities that might arise while shaping the future of the world.

Data availability statement

The datasets presented in this article are not readily available because the informed consent was provided by participants under the condition of anonymity and confidentiality of their answers. Requests to access the datasets should be directed to CC-Z, claudia.camacho@tec.mx.

Ethics statement

Ethical approval was not required for the studies involving humans because no personal or identifiable information was provided by the participants and ethical approval is not required under the local legislation of the institutions that took part in this research. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

CC-Z, JN-F, and IK contributed to the conception and design of the study. IK collected the data. EM-E conducted the data processing and analysis. EM-E, JN-F, and CC-Z wrote the manuscript. 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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