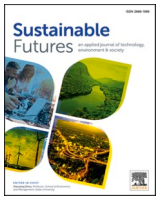
Sustainable Futures 10 (2025) 100851

Contents lists available at ScienceDirect

Sustainable Futures

journal homepage: www.sciencedirect.com/journal/sustainable-futures



Impact of digitalized-education upon sustainable education and practice: A systematic review and meta-analysis of literature based on pre-intra-and-post pandemic and rural education development

Kingsley Okoye [a,d], Esmeralda Campos [a,b], Amit Das [c], Varsha Chakraborty [c], Mahuya Ghosh [c], Amlan Chakrabarti [c], Samira Hosseini [a,e,*]

[a] Writing Lab, Institute for Future of Education, Tecnologico de Monterrey, Monterrey, Nuevo Leon CP 64849, Mexico
[b] Austrian Educational Competence Center Physics (AECCP), University of Vienna, 1090 Vienna, Austria
[c] School of Information Technology, University of Calcutta, India
[d] Department of Computer Science, School of Engineering and Sciences, Tecnologico de Monterrey, Monterrey, Nuevo Leon CP 64849, Mexico
[e] School of Engineering and Sciences, Tecnologico de Monterrey, Monterrey, Nuevo Leon CP 64849, Mexico

ARTICLE INFO

Keywords:
Digital technology
Higher education
COVID-19
Digital divide
Rural area
SDGs
Educational innovation

ABSTRACT

This study identifies the pedagogical impact and opportunities to the use of digital technologies in education. It applies the PRISMA methodology to investigate the available literatures by identifying potential barriers, challenges, and opportunities to the use and adoption of the *digitalized-education,* taking into account the pre-, intra-, and post-pandemic era and rural education development. By covering a seven-years period between 2017 and 2023, the study analyzed the modest contributions and pedagogical impact of the selected studies ($n = 324$) retrieved from the Scopus and Web of Science (WoS) databases. The data analysis include trend examination, geographical and contextual diversity of the dataset, and thematic synthesis of digital technologies' benefits, challenges, and implementation in context of COVID-19 and rural education. This was done using methods such as Concept mapping and Text mining by leveraging data visualization and analytics tools: VOSviewer, Tableau, and R Statistics software. The study identified "digital divide" attributed to lack or limited access to digital (learning) technologies, and online educational platforms or resources as the main challenge to the effective adoption of digitalized-education, and attainment of quality of education and its delivery by the educators, particularly in the remote or resource-limited regions. The study empirically sheds light on the theoretical and practical implications of the key findings and result upon a *scalable* and *sustainable* education and practices, particularly in line the UN's sustainable development goals (SDGs) that are directly related to the quality of education, including reduced inequalities across the educational communities and/or a development-oriented educational society.

1. Introduction

Digital technologies has proven its importance in education and the underlying teaching and learning process [1–5]. There is evidence that the new and emerging "educational technologies" are didactically effective, for instance, during the recent global pandemic [6–8]. However, existing studies have revealed the need to strengthen or heighten the teaching/learning processes to include the innovative learning technologies, and ensure adequate and equitable access to the digital platforms and infrastructures for the different stakeholders [3,9,10]. There is still scientific debate on how disproportionate or slow the educators may be in adopting the digital technologies for acceleration and transformation of the educational ecosystem [2,3,11,12]. For example, people living in rural areas, worldwide, often face challenges of gaining quality education at all levels, and are less likely to follow through higher education [10,13,14]. Consequentially, the so-called "systematic divide" prevents people in the rural areas or indigenous societies from developing their full potential and improving their living conditions [15–18].

To break the cycle and heighten the impact of higher education, particularly toward a *scalable* and *sustainable* education [19,20], improving the digital access and quality of education in the rural areas

* Corresponding author at: Writing Lab, Institute for Future of Education, Tecnologico de Monterrey, Monterrey, Nuevo Leon CP 64849, Mexico.
E-mail address: samira.hosseini@tec.mx (S. Hosseini).

https://doi.org/10.1016/j.sftr.2025.100851
Received 1 July 2024; Received in revised form 15 January 2025; Accepted 11 June 2025
Available online 12 June 2025

or resource-limited regions, is essential [10,14,15,21]. Those (technological and didactical) goals have been severely accentuated by the recent COVID-19 pandemic [8,22,23]. During the pandemic, higher education and learning has shifted to remote (digitalized) settings through the use of technologies [22,24]. However, it is particularly challenging for people in the rural areas to access quality education due to lack of technological resources or adequate access to the online learning tools and platforms [14,15,25]. The United Nation (UN) highlighted the toll that the COVID-19 pandemic has left, e.g., regarding the SDG goals 4 and 10 [26] by anticipating an increase in student' dropout rates, increase in learning inequalities particularly in the vulnerable communities, need for sustainable access to affordable network and infrastructures, development-oriented policies, and social links and barriers between the rural vs urban areas [12,27–31]. These are critical factors covered in this study (see Section 2, Table 4) that idiosyncratically stands and represents in alignment with the UN's global sustainability goals [26]; the creativity, knowhow, technology and resources needed from all of society or in this study's context [32], considered necessary to achieve the SDGs, as well as the fact that the development and action plans by the stakeholders (researchers, educators, governments, fundings agencies, policymakers) must be prolifically designed to balance social, economic and environmental sustainability [26,32], such as the one done in this paper.

In these perspectives, this study notes that it is imperative to research and study the pedagogical impact and implications of the digital technologies' use, and the potential challenges before, during, and after the COVID-19 pandemic, particularly for rural education development. To uncover and address the existing challenges and gaps in the available literature, we conducted a systematic review and meta-analysis of the literatures to summarize both the current state-of-the-art and best practices in implementing the digital technologies in education, referred to as *digitized-education* in this study. Two critical contexts were analyzed (i) the pre-intra-and-post pandemic era, and (ii) rural education development. By Pre-Covid, the authors refer to studies that dealt with the use of digital technologies in education before the COVID-19 outbreak (between 2017 and 2019). Intra-Covid refers to the period or peak of the pandemic (between 2020 and 2021). While Post-Covid refers to the period in which the pandemic has dwindled and a lot of institutions and educational organizations are reverting back to in-person or hybrid learning modalities (between 2022 and 2023) [1,24,33]. Also, it is important to mention the fact that the study has included the margin of studies in the year 2019 between the Pre-Covid and Intra-Covid to allow the review cover the time in which the Covid-19 outbreak started in late 2019 [34] and the time in which it was officially declared a pandemic in early 2020 [35]. Therefore, to this end, this review covered a seven-year period by exploring the published peer-reviewed papers in the topic between 2017 and 2023.

1.1. The rationale of the study

We conducted a systematic summary of existing literature on the use of digital technologies in education; pre-intra-and-post pandemic era and rural education development using the PRISMA methodology.

The research questions of the study are:

1. To what extent has the existing literature addressed the use of digital technologies in education considering the pre-, intra-, and post-pandemic and rural education development?
2. What are the socio-technical and pedagogical implications of the digitalized-education upon sustainable education and practices taking into account the pre-, intra-, and post- pandemic and rural education?
3. How can the main factors and findings be used to foster a scalable and sustainable education and practice?

The main contributions of this study include:

1. It present a systematic review and summary of existing literature in the use of digital technologies in education covering the pre-, intra-, and post- Covid-19 pandemic era.
2. It identify the key factors (e.g., digital divide) to why the digitized-education may or may not be effectively implemented in the rural areas.
3. It determine the opportunities, issues, and challenges to attainment of quality education directly in line with the UN's global sustainable development goals (SDGs).
4. It empirically shed light on how the digital technologies and the accompanying transformations can help provide solutions to the ever-increasingly need to innovate and advance the teaching/learning processes, in lieu of the post-pandemic education or modern-day education.
5. It demonstrate the capability of using data-structure approach such as the Text mining technique in conducting educational research and meta-analysis.

2. Background information

2.1. Digital technology in education: pedagogical perspective

Instructional -wise, the use of digital technologies for education requires proper design and integration of materials that are tailored for effective learning [36]. Technologies such as Virtual classrooms (Zoom, Google Meet, Jitsi Meet, Cisco Webex, Starleaf, Google Hangouts), video conference, TV, radio, augmented reality (AR), metaverse, virtual reality (VR), robots, chatbots, learning analytics, etc. [37,38], are widely used for providing a more inclusive learning environment and experiences for the students. These technologies has proved to enable educators to guide the students' learning process, monitor their daily activities, and encourage them through virtual rewards (animated smileys, stars, badges, recognitions, etc.) [39,40]. The teachers can boost motivation and engagement of the students during the learning process through technologies like augmented reality (AR), videos, and podcasts to keep the students eager to learn [41–43]. Through analysis of student's feedback, teachers can also steer and tailor digital offerings to students' convenience or need [44,45]. Moreover, self-learning opportunities for the students have shown to enhance drastically due to digitized-education [46]. In connection to the emerging societal and technological need, digitalized-learning have sustained and proven to strengthen the knowledge acquisition process of learners [40,47,48]. With digital education, knowledge dissemination has become seamless even in the unprecedented recent pandemic and beyond [8,24,49]. Access to learning resources in rural vs urban contexts is also starting to close, together with infrastructural grapples [48].

However, it can be noted that digital technology and the various online platforms was the most effective means by which the educators were able to continue learning, e.g., during the recent global pandemic [24,40]. Therefore, it is noteworthy to mention that the resultant innovations are anticipated by the different organizations and institutions concerned with education and its delivery, to come with challenges and opportunities [1,48,50–52]. Some of the noted challenges range from issues that has to deal with the need for using the new and emerging technologies to nurture rapid learning-recovery or reinstatement of the teachers and students (post-pandemic education), to instruction-design and the challenge for educators to act and adopt suitable turn-around policies to support the quality of education and continuous learning for the learners [1,53–57].

2.2. Digital technologies in rural education and development

Understanding the main factors that impact the use of digital technologies in the indigenous communities is important for a holistic overview and scalable adoption of the digitalized-education, globally. Educational research in the rural context has brought to light

protuberant factors that the teachers and students may face in terms of gaining quality education [27,42,58–62]. For example, in the past, Young [62] noted that students in rural schools have lower academic achievement than their counterparts in urban schools, and they tend to drop out from school before reaching higher education [63]. Quite often, the differences between academic achievement in the rural vs urban contexts are related to difficulties that students in the rural areas need to overcome daily, including educational infrastructure investment and geographic isolation [10,12,14,15,64]. Social exclusion, digital exclusion, and accessibility are all important underlying factors associated with the "digital divide" problem or issue in rural higher education [15,65,66]. Talib et al. [66] highlighted inequality and inaccessibility to the digital infrastructure as a disadvantage student in the rural areas faced during the recent COVID-19 pandemic. Therefore, while the use of digital technology in education can provide a way to reduce the gap between the rural vs urban education, the *digital divide* presents a challenge, in itself [11]. There is still so much to uncover or learn about the several practices that higher education institutions, worldwide, implemented during the COVID-19 pandemic, that can be (scalable and sustainably) applied in the rural contexts as long-term strategies to the inaccessibility to infrastructure and learning loss they largely experienced during those period [1,2,67,68].

Digital divide is the primary challenge to digitalized-education in the rural areas [10,14,15,69]. Infrastructural limitations and lack of remote learning facilities (digital equipment, internet, etc.) has a huge impact in the rural, or yet, low-tech and marginalized regions [69,70]. In terms of learning resources, the rural and economically disadvantaged (low-tech or resource-limited) communities experience disparities in accessing the digital resources, and thus, tend to disconnect from continuous opportunities to education [10,15]. Inadequate online videos and course materials in native languages is also a barrier, and demotivates the students in those (rural) settings, including high cost of internet connectivity and networks [33]. From the teachers' point of view, limited or lack of digital skills tend to make the indigenous people hesitant towards participating in online or distance education [42,60,71,72]. Although, recently, some NGOs (non-government organizations) are helping the teachers to gain proper training and digital skills/tools to move towards digitalization [73]. For example, educational organizations such as UNESCO [48] have enlisted in its National Learning Platforms and Tools [48], some modern tools and e-resources that are used to foster continuous learning for the teachers and their students, across the various regions and countries, particularly during the recent pandemic. Apparently, those types of learning initiatives and platforms facilitates reduction in learning costs, offering unabated professional development, and enhancing the scope of distance learning to reach the indigenous societies [74]. The recent COVID-19 pandemic necessitated an open, inclusive, and proper use and application of the digital learning tools, platforms, and resources within the educational ecosystem at large or globally [1,2,40,48,51,55,56,75–77].

2.3. Digital technologies in education: pre- intra- and -post COVID-19

Significant (technological) changes and transformation has been achieved in education as a result of the recent COVID-19 pandemic [40]. Although its future scope with a blended approach (e.g., technology-enhanced learning) is yet to be fully realized and sufficiently documented [55,78–80]. In pre-COVID-19 days, most teaching models followed the traditional classroom methodology, and many of the developing countries were faced with lack of infrastructure and opportunities to the digitalized-education [81]. During pre-COVID, there was rising need to comply with alternative approaches or methods for using the digital platforms for learning. Then the outbreak of COVID-19 brought into light and practice, the challenge of ensuring uninterrupted learning through technology [40,82].

The lockdown and self-isolation compelled the rapid shift from the traditional methods of learning (face-to-face, peer-to-peer, etc.) to the virtual/remote learning, alongside the need for non-stop learning [24,83]. The COVID-19 acted as a catalyst to make the teachers, students, teaching staff, and other stakeholders acquainted with the e-learning process to a great extent [44]. During the transition from offline to online education [84], there was (i) an increased need for digital assets for creating and offering distance education and collaborations [40], and (ii) an inclination for the different stakeholders to learn advanced technologies and assessment tools, including familiarity with the cloud spaces for self-learning [85]. There was also a huge gap in disseminating the digital technologies in the developing countries due to the disparities and unequal distribution of the global government educational investment and expenditures [12,17,82,86]. Robust digital resources and seamless access to internet with affordable price, including network infrastructure are still compounding educational challenge worldwide [33]. Adequate action plans and initiatives are to be adopted by the various governments particularly in the developing countries to accelerate the "digitized-education" [40,48,50,81,87].

Entering equitable digital transformation can guarantee immense opportunities, offer new capabilities to the imminent society, and help take the world to a new learning era in anticipation to the post-pandemic education [18,50–52,56,76,77,88]. Eventually in the already emerging post-COVID-19 education era, there is tremendous emphasis to continue with the fast, resilient technology-enhanced learning (TEL-based education) all over the world [17,40,51,52,55,56,75–77,89,90]. Interestingly, effectiveness of the much-needed blended learning or hybrid approaches will be appreciated in the education ecosystems, worldwide [24,46].

To summarize our review of the literature, the existing studies have shown that *digitized-Education* comes with challenges in its adoption and/or application within the entire domain of teaching and learning [3,10,40,50,51,55,67,77,79]. The "digital divide" otherwise allied to the learners or regions lacking access to the digital infrastructures, who are excluded from the vast benefits and opportunities to learning, has been uniformly highlighted in majority of the studies [2,3,10,14,15,40,51,79]. With over 500 million students estimated to have no access to the digital or online learning resources [79], and learning poverty or loss (lack or limited access to learning infrastructures, training, and skills) increasing from 53 % to 63 % globally, particularly as a result of the recent global pandemic [1]; we note that educational organizations such as OECD [54,57,67] and UNESCO [27,31,91] have highlighted the risk in lower-income or low-tech countries falling behind in reaching the objectives of Education 4.0 or sustainable education/practices [92–94]. In turn, widening the technological gap or "digital divide" per se [3,10,25,95]. In practice, collective development of effective "innovative educational frameworks or mandates" is needed [96–99]. The attention of the different governments and educational institutions must be drawn to pay a great deal of it to new and better ways or models for achieving a *scalable* and *sustainable* TEL-based (technology-enhanced) education that meets individual needs of the learners in the diverse hemispheres [24,31,55,56,100–102]. Educators, governments, researchers, policymakers, and the different stakeholders, should commit to reimagining or rethinking the pedagogical practices toward an effective adoption of the TEL-based (digitized) education addressed in this study context [51,55,103].

3. Methodology

This study used a set of inclusion and exclusion criteria the authors developed using the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) methodology [104–107] by adhering to the recommended processes for educational research [108–110] in its investigation. The PRISMA method was used to search for the existing literature and synthesize key factors (COVID-19, Rural Education, Sustainability) as it concerns the use of digital technologies in education based upon the research questions of this study (see Section 1.1).

3.1. Search process

The search for relevant peer-reviewed studies in the topic was done in two most popular international databases (Scopus and Web of Science) that houses publications and research on topics related to the *digital technology* and *education,* by taking into consideration their wide range of coverage and relevance in the field. The literature search was conducted on the 9th of January 2024 by extracting available publications in the topic for a seven-year period between 2017 and 2023, covering the pre- intra- and post-Covid-19 era and rural education development. The keyword and search terms used in the systematic search and selection of the literature is described in Table 1 and Fig. 1, respectively.

3.2. Inclusion and exclusion criteria

The results of the search process and criteria for selection of the relevant papers was based on the PRISMA workflow explained in Fig. 1 and Table 2.

As illustrated in Fig. 1, and explained in Table 2, the process for inclusion and exclusion of the literatures using the PRISMA methodology are described in detail (Table 2).

3.3. Search outcome and method for data analysis

Retrieving the relevant literatures (see Table 1 and 2, Fig. 1) was based on the search we conducted in the electronic databases (Scopus = 404 paper, and Web of Science = 144 papers) which resulted in a total of $n = 548$ papers. The authors examined the extracted papers on the grounds of their perceived appropriateness and relevance considering the identification and screening criteria, i.e., title of the paper, availability of full-text, domain, year of publication, and peer-reviewed, after removing the duplicates (Table 2, Fig. 1). This process resulted in a further $n = 190$ papers being excluded (Fig. 1). It is important to mention, considering the fact that the same paper in one database, e.g. Scopus, can also be retrieved or found from the other (Wos), that during the identification and screening process, the result of the two databases (Scopus and WoS) were merged and the duplicate titles and papers removed. The full-text of the remaining 358 articles were downloaded, the Abstracts read, and reviewed by the authors. After reviewing the selected papers ($n = 358$) taking into consideration the eligibility and inclusion criteria (e.g., context and scope of the study, i.e., digital technologies, rural education development, COVID-19, quality of information and alignment with sustainable education), a further $n = 34$ papers were excluded resulting in a total of $n = 324$ articles finally included in this systematic review and meta-analysis synthesis. Considering the rigor of the selection and screening process, and the data reliability, it is important to mention that the multiple authors have independently reviewed the extracted papers and the final dataset.

The data analysis and synthesis of the data ($n = 324$) includes trend examination, geographical and contextual diversity of the dataset, and thematic synthesis of the digital technologies' benefits, challenges, and implementation within the context of COVID-19 (pre-intra-post) and rural education development. This was done using methods such as Concept mapping [111–115] and Text mining method [116–119] by leveraging data visualization and analytics tools such as VOSviewer [120,121], Tableau [121], and R Statistics [122] software. The data analysis methods and results are presented and described in detail in the next section (Section 4)

Table 1
Search terms used in the bibliometric search and extraction of the relevant studies from the electronic databases (Scopus and Web of Science).

Scopus database ($n = 404$ papers found), Web of Science ($n = 144$ papers found)		
Search Component	Search Term	Component Description
Search Component 1	("Digital technology" OR "Digital technologies" OR "e-learning" OR "distance learning" OR "digital education" OR "educational technology" OR "educational technologies" OR "edtech" OR "technology-enhanced learning" OR "learning analytics" OR "learning technology" OR "learning technologies")	Used to extract existing literatures on Digital technologies and education
Search Component 2	AND ("Covid-19″ OR "corona virus" OR "pandemic" OR "pre-covid" OR "post-covid" OR "rural area" OR "low-tech" OR "remote area" OR "developing country" OR "traditional education")	Includes studies that focuses on the context of Covid-19 or rural education
Search Component 3	AND ("sustainable education" OR "outcome-based education" OR "sustainable development goal" OR "SDG4″ OR "quality education")	Includes studies that focus on sustainable development or quality education
Search Component 4	AND PUBYEAR > 2016 AND PUBYEAR < 2024	

4. Data analysis and results

The following are the results of the data analysis and synthesis of the selected papers ($n = 324$) in the use of digital technologies in education considering the key factors (COVID-19, Rural Education Development, and Sustainability) (Figs. 2 to 10).

4.1. Year of publication

The following bar chart (Fig. 2) shows the distribution of the selected publications ($n = 324$) by year (2017–2023) done using the Tableau software [121].

The results in Fig. 2 show an unsteady and relatively low growth in research in digitalized-education Pre-COVID (2017–2019) with only 4 publications in 2017, 11 in 2018, and 5 in 2019 (Fig. 2). This indicates a slow growing, but yet modest interest in digitalized education before the pandemic. However, the rise in publications in 2018 (Fig. 2) could suggest an early recognition of digital tools' potential in education, likely driven by technological advancements [81,123–125].

The sharp increase during the pandemic (2020–2021) indicates a significant rise in publications, 2020 (37 studies) and 2021 (76 studies), correlating with the onset and continuation of the impact of the COVID-19 pandemic in education [2,6,8,22,48,77]. This surge reflects the urgent global shift toward digitalized-education, as traditional systems were disrupted by the lockdowns and school closures [8,22,23,126].

The year 2022 (106 papers) and 2023 (87 papers) shows the peak and highest number of publications (Fig. 2). This result is expected, since the impact of the COVID-19 and the resultant innovations that has spanned as a result of the outbreak has triggered the interest of many researchers and educational organizations [8,33,45,127–132]. This indicates an intense focus on evaluating and understanding the implementation and impacts of digital education systems established during the pandemic, as an aftermath and in lieu of the post-pandemic education [56,101]. The sustained high numbers,2022 (106 papers) and 2023 (87 papers), reflect ongoing interest in optimizing digitalized education for long-term sustainability within the education ecosystem [45,101,102,133].

The insights that can be drawn from this result (Fig. 2) include the fact that the pandemic has served as a catalyst for research in this topic [15,67,72,114,126,134,135]. The COVID-19 pandemic served as a major turning point for research into digitalized-education, accelerating both the adoption and critical evaluation of such systems, particularly in the rural context [15,17,67,114,126,134,136] explored in this study. The peak in 2022 and 2023 may reflect a focus on post-pandemic

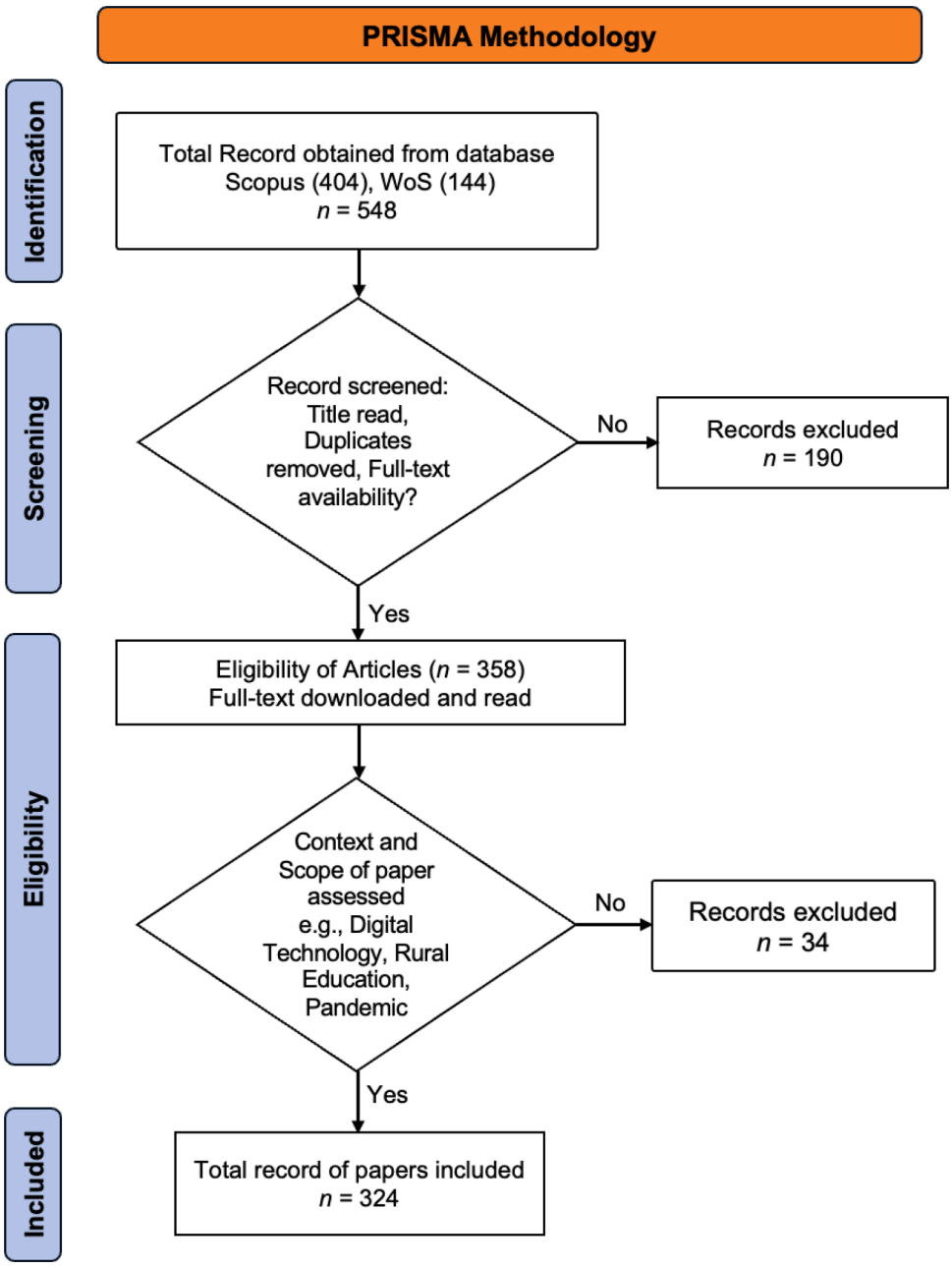


Fig. 1. PRISMA Methodology used in selection of the relevant literatures (inclusion/exclusion criteria).

education and recovery, with studies assessing the efficacy and sustainability of the emergency digital learning solutions and impact in education [45,55,61,101,137]. This factor, idiosyncratically, uncovers the shift in research priorities, offering room for further exploration of long-term strategies to integrate digitalized-education into sustainable education systems. Likewise, the low publication count before 2020 (pre-Covid) (Fig) highlights the limited emphasis on digital education research prior to the pandemic, that in turn, provides an opportunity to retrospectively investigate or analyze pre-pandemic research gaps and lessons learned across time, which could form another direction for future research. Moreover, the post-pandemic research can focus on addressing the issues with *digital divide* or access disparities, especially in low-tech or resource-limited settings [77,138] highlighted in this study.

4.2. Country representation

The world map (individual country distribution and frequency chart) in Fig. 3, done using the Tableau software [121], highlights a significant disparity in research contributions among the different countries and geographical dispositions.

As shown in Fig. 3, countries such as India (31 publications), Spain (27 publications), and China (21 publications) are leading contributors in the topic (Fig. 3). This indicates a concentrated focus on digitalized-education in those regions (Asia and Europe) [12], likely due to their strategic investments in educational technology and a high demand for sustainable education reforms, policies, and research agenda during and after the pandemic [12,139–141].

Moderate contributions from countries such as Russia (16), United States (14), Malaysia (14), United Kingdom (11), and South Africa (11) (Fig. 3) shows active involvement in digitalized education from those countries or region, but who may also face barriers in scalability or localized research impact [16,83,142–147].

The combination of developed and emerging economies and countries such as Australia, Saudi Arabia, Jordan, Philippines, Italy, Bahrain,

Table 2
Inclusion and exclusion criteria for selection of relevant literatures.

PRISMA	Inclusion/ Exclusion Criteria	Description	Inclusion/Exclusion Process Explained
Identification and Screening	Timeframe	Selected papers published between 2017 and 2023	**Inclusion:** Aim for papers published between 2017 and 2023 to ensure contemporary relevance and reflection on digital transformation within the education context. Timeframe captures the impact of the COVID-19 (before, its onset, and ongoing recovery phase) aligning with the study's focus on pre, intra-, and post-pandemic developments in rural education. **Exclusion:** Exclude articles outside this range (2017–2023), as they may theoretically lack relevance to the current technological and educational transformation and advancements, e.g., influenced by the recent pandemic or rural education and development in modern society.
	Manual Verification of Topic	Check whether title/description of article is related to digital technology or education	**Inclusion:** Ensure articles explicitly relate to digitalized education, sustainable education practices, and/or their intersections with rural development. Focus on studies and strategies implemented pre-, during and after the pandemic, e.g., to enhance education access and sustainability. **Exclusion:A**articles with a vague connection to digital technology or education are removed, such as those emphasizing unrelated technological fields to education or urban-centric educational studies without transferable rural insights.
	Overlap	Removing duplicate articles	**Inclusion:** Retain unique studies with distinct perspectives, methodologies, or findings that contribute to understanding digitalized education's impact on sustainability and rural education development, and/or Covid-19. **Exclusion:** Exclude duplicate studies to avoid redundancy or bias in the synthesis process, and ensuring a concise and cohesive dataset.
	Accessibility	The full-text article is available as open access or through authors' institutional access	**Inclusion:** Prioritize accessible articles to ensure comprehensive data for review. include studies with full-text availability via open access or institutional platforms, ensuring a sufficient data for critical analysis. Open repositories or journals are considered to maintain transparency and reproducibility. **Exclusion:** Exclude articles unavailable in full text or behind paywalls without institutional access.
	Source/ Database	Whether chosen articles have undergone scientific peer-review with digital object identifier (DOI) or source by reputable publisher	**Inclusion:** Prioritize and retian peer-reviewed studies indexed in the reputable databases (Scopus, Web of Science) to ensure credibility. Focus on works with DOIs to enhance traceability and reliability. **Exclusion:** Exclude non-peer-reviewed contents, or articles from predatory journals to maintain scientific rigor.
Eligibilityand Inclusion	Relevance	Study related to digital technology and education, COVID-19 and/or Rural context, and sustainability	**Inclusion:** Include studies that explore or addresses digital technology's role in education based on the Covid-19, sustainability, or rural contexts. Emphasize works exploring innovative educational models and methods, digital gaps, and adaptations specific to the above factors. **Exclusion:** Exclude irrevant studies with minimal focus on the topic, such as those discussing digital technology in non-educational or non-rural settings.
	Quality of Information	The study clearly describes the method/approach and main findings or contributions to the topic area and domain	**Inclusion:** Focus on high-quality studies that clearly articulates implications for sustainable digital education based on the research design, methodologies, and

(*continued on next page*)

Table 2 (*continued*)

PRISMA	Inclusion/ Exclusion Criteria	Description	Inclusion/Exclusion Process Explained
			findings. Retain works with robust data, thorough discussions, and actionable recommendations. **Exclusion:** Exclude poorly written or underdeveloped studies lacking methodological rigor, clear objectives, or contributions to the research field and topic.
	Methodology	Methodology of the study contributes to the research questions and objectives	**Inclusion:** Emphasize studies employing robust methodologies, such as systematic reviews, case studies, or mixed methods, to provide nuanced insights into digitalized education (Covid-19 impact, remote education, and sustainability). **Exclusion:** Exclude articles with inadequate or weak methodologies or unclear objective, e.g., lack of methodological transparency, or inadequate sample sizes.
	Alignment with SDG goals and target	Article contributes to improving quality of education, or educational society and practices	**Inclusion:** Retain studies contributing to SDG 4 (Quality Education) and other directly related sdg goals and target (SDG 10, 11, 17) focusing on educational equity, digital access, and sustainable teaching practices, particularly in rural and underprivileged contexts. **Exclusion:** Exclude studies lacking alignment with sustainability or broader societal impacts on education.
	Implications for Practice	Study reports a roadmap for adopting digital technologies in education, during or as aftermath of the COVID-19 pandemic and/or rural context	**Inclusion:** Emphasize studies offering actionable insights, strategies, or frameworks for leveraging digital technologies in sustainable rural education. These include roadmaps for post-pandemic education and recovery or enhancing access to marginalized groups. **Exclusion:** Exclude works with no practical implications or relevance to the topic (Covid-19 impact, rural education, and sustainability).

Mexico, and Morocco are among countries that contributed between 9 and 5 papers, respectively (Fig. 3). This may be due to their respective government and educators focus on improving access to digital learning tools and prioritization of technology-driven education reforms, including active participation in global initiatives aimed at improving education in the resource-limited contexts [15,16,148–154]. There is also evidence on lessons learned by the emerging economies from the educationally-advanced countries [143,155,156].

Underrepresented regions which include several countries, especially from developed countries like Canada, Switzerland, and Africa (e.g., Zambia, Senegal), including smaller nations (e.g., Bosnia and Herzegovina, Fiji), etc., exhibit minimal research contributions from these regions (Fig. 3). This suggests a lack of resources, infrastructure, or focus on digital education's role in fostering sustainable educational practices, and/or addressing challenges with the digitalized-education and policies that may be faced by those countries, individually, which hinders their capacity to contribute significantly to global research in this field [22,81,157,158]. This observed disparity can form further areas for research, particularly those that may focus on uncovering the individual country-specifics in this topic.

In summary, considering the global trends and gaps; while Asia, Europe, and North America dominate the research output (see Fig. 3), there is a significant gap in contributions from the Global South, particularly Sub-Saharan Africa, Latin America, and smaller island nations (Fig. 3). This idiosyncratically reflects unequal access to research funding and educational technologies [11,12,159]. Such outcomes unveil the importance of bridging the gap between technologically advanced nations and underrepresented regions within the realm of "digitalized-education research and investment" [3,11,12,131,160]. The global emphasis should shift towards fostering inclusivity, building digital capacity in developing nations, and ensuring that sustainable education practices reach rural and underserved communities [76,77,158,160,161].

The insights and lessons from the above results (Fig. 3) include encouraging funding and collaborations to promote research and address the gaps in underrepresented regions, especially Africa, Latin America, and small island developing states (SIDS) [12,14,161–163]. International partnerships (e.g., GPE, UNESCO, OECD, and World Bank initiatives) can also aid in equitable resource allocation, and expand research in rural education to ensure inclusivity and reduce digital divides [1,11,40,54,55,77,88,129,130,160,164,165]. Other key factors include emphasis on contextual solutions considering socio-economic and cultural differences. This is owing to fact that digital education success may be context-dependent, as strategies effective in urban context might differ from those needed in the rural context [157,158,166,167]. Research indicates that inclusive policies yield better long-term educational outcomes [18,77,127,130,158]. Governments, educators, and international agencies should prioritize investments in digital infrastructure and teacher training, particularly in the rural and resource-constrained areas [2,12,55,58,75,165,168,169]. This is critical to bridging the potential and underlying gaps identified in the countries with lower contributions (see Fig. 3).

4.3. Publication source

The synthesis for publication source of the selected literatures (n = 324) is presented below (Fig. 4).

The bar chart (Fig. 4) illustrates the number of publications from

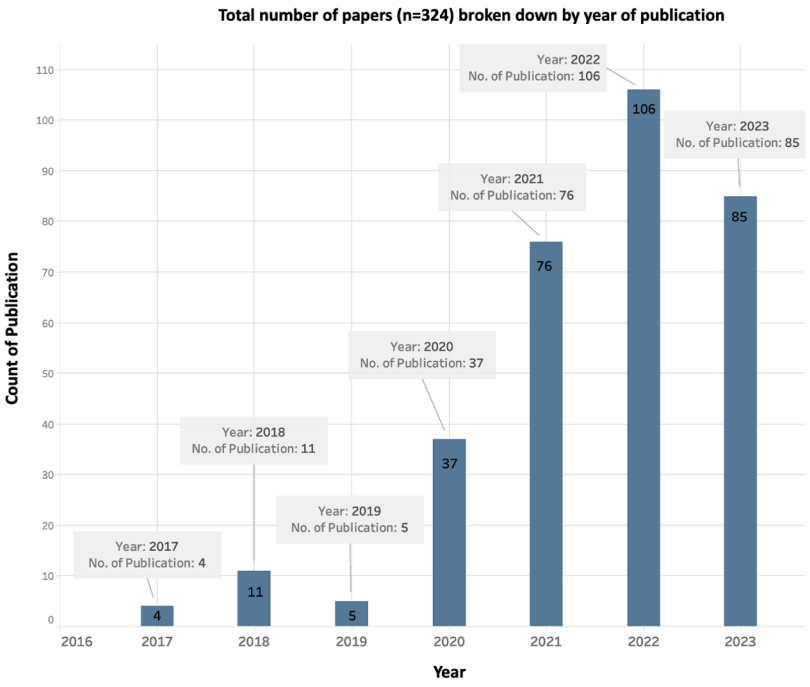


Fig. 2. Distribution of selected papers (n = 324) broken down by year of publication.

various sources in the topic. The journal "*Sustainability*" is the leading source, contributing 36 publications (see Fig. 4). This dominance reflects the topic's strong alignment and the journal's focus on sustainable practices and interdisciplinary approaches related to the field. This finding indicates that research on digitalized education is increasingly framed within the context of global sustainability goals, particularly SDG 4 (which promotes Quality of Education) and SDG 10 (which promotes Reduced Inequalities) [170,171].

The significant contributions from Conferences such as the ACM International Conference Proceedings Series (11 publications) and Lecture Notes in Networks and Systems (9 publications) highlight the critical role of conferences in disseminating cutting-edge research on the digital education technologies. These platforms promote technical and implementation-oriented studies [93,172]. Conference proceedings often explore innovative tools, e.g., digital frameworks and methodologies, thus, making them pivotal for addressing the rapidly evolving field of educational technology, and platform for sharing new and innovative ideas on the topic [93,172].

Another key finding of this study (Fig. 4) include educational journals with focus on *pedagogy*. Journals such as Education Sciences, Frontiers in Education, and Educational Technology Research and Development (each contributing 3–4 publications) (Fig. 4) highlights the relevance of digitalized education to modern pedagogical theories and practices. These publication sources have proved to address the effectiveness of digital tools in enhancing teaching and learning outcomes, particularly during the pandemic and within the rural education context [43,113,148,173–177].

Considering interdisciplinary aspects, contributions from journals like Soft Computing, Medical Science Educator, and World Sustainability Series (2 each) (Fig. 4) demonstrate the interdisciplinary nature of the topic, linking digital education and COVID-19 to other areas like computational technologies and health education [22,38,68,139,178,179].

It is also noteworthy to mention the fact that while this review was positioned to explore rural education development, there was minimal representation from journals focusing explicitly on the rural or underdeveloped regions (Fig. 4). This emphasizes a gap in research dedicated to addressing the challenges of digital education in the rural contexts, which form one of the main contributions of this present study. However, the clustering of publications around *sustainability* and *digital education* reflects the heightened attention the field has gained post-pandemic, as institutions worldwide continue to adapt remote learning solutions [24,180–182]. This shift has been instrumental in bridging the gap in education during crisis or disruptions, albeit with varying levels of success based on regional and socioeconomic contexts [3,22,79].

In summary, predominance of publications in journals like "Sustainability" suggests that digitalized-education is viewed as a global enabler of sustainability, fostering inclusivity and equity in education systems [22,59,100,183–189]. The relatively low contribution from rural education-focused journals or sources indicates a need for regional and rural focus, and an opportunity for further exploration of how digital education technologies can address the rural-urban divide [3,71,190]. Efforts should be made to disseminate research findings across a broader range of journals, particularly those focused on rural development, global education equity, and social justice. Data indicates opportunities for interdisciplinary research, especially in areas such as artificial intelligence, machine learning, and their applications for the future of education and/or educational sustainability [45,173,191–194].

4.4. Language of publication

The chart in Fig. 5 is the result of the synthesis and analysis of the main publication language for the selected studies (n = 324).

The chart in Fig. 5 indicates that majority of the studies (310 out of 324) were published in English, accounting for approximately 95.7 % of the total reviewed articles (n = 324). This overwhelming dominance highlights the prevalence of English as the primary academic language in global research dissemination. Only a handful of studies were published in non-English languages: Spanish (9 publications), Croatian and Portuguese (2 each), and Chinese (1 publication). This imbalance suggests limited representation of research conducted or reported in non-English-speaking regions, which may result in underrepresentation of localized educational practices, challenges in digitalized education, or underrepresentation of countries in the developing or resource-limited

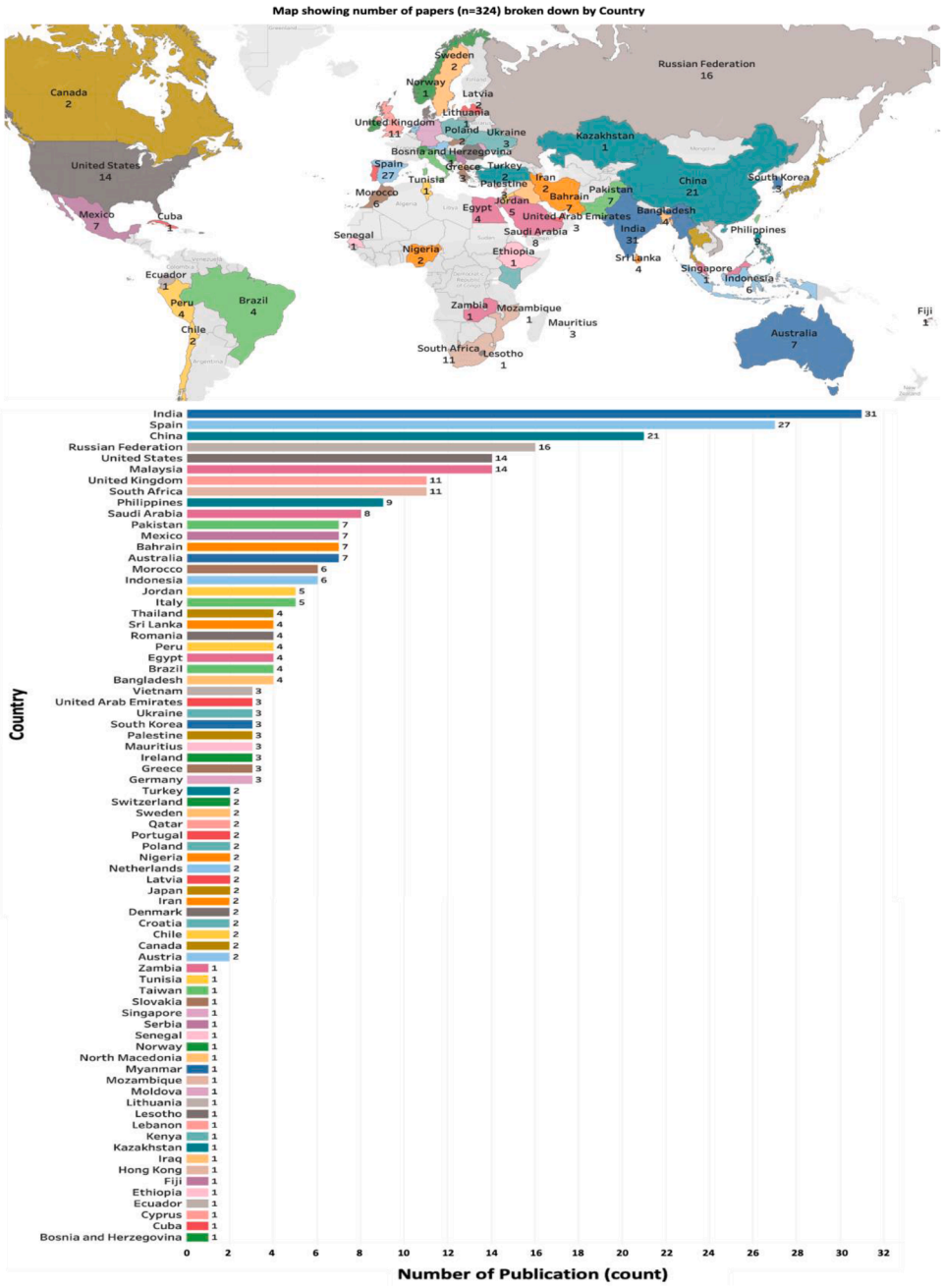


Fig. 3. Studies in use of digital technologies in education (n = 324) broken down by Country.

regions, as also found in the individual countries' analysis in this study (Section 4.2).

Considering the implications of this result (Fig. 5); for Rural Education and Pandemic Contexts, it can be said given the global nature of education, that the language barrier may hinder inclusive insights into rural education or the unique challenges faced in non-English-speaking countries during the pandemic [15,40,48,58,60,167]. Language diversity could enrich the availability of knowledge and scientific resources in the use of digital technologies for education [48], particularly in the remote regions, by promoting and incorporating perspectives from authors from the diverse socio-cultural and educational contexts [195,196].

4.5. Author keywords, title, and Abstracts (network analysis)

In Fig. 6, the authors performed a bibliometric mapping of the Authors' keywords using the VOSviewer software [120].

As shown in Fig. 6, it can be clearly visualized, the consistency and connection between the main subjects related to this topic (such as e-learning, digital education, COVID-19, and developing countries) which triangulates with the research questions and objectives incorporated in the systematic search and terms used in this study (see Sections 1.1 and 3.1). While the central link is focused on "COVID-19″ and "e-learning" (Fig. 6), keywords like "sustainable education" and "developing countries" points to the persistent barriers to quality education, particularly in the rural or resource-limited settings [3,10,14,90,163].

Furthermore, in Fig. 7, the authors performed a bibliometric mapping and network analysis based on text contained in the Titles and Abstracts of the analyzed studies (n = 324) by considering a minimum of combined 10 top term occurrences in the Title and Abstracts using the VOSviewer [120].

The Title and Abstract-based Concept network analysis (Fig. 7) show

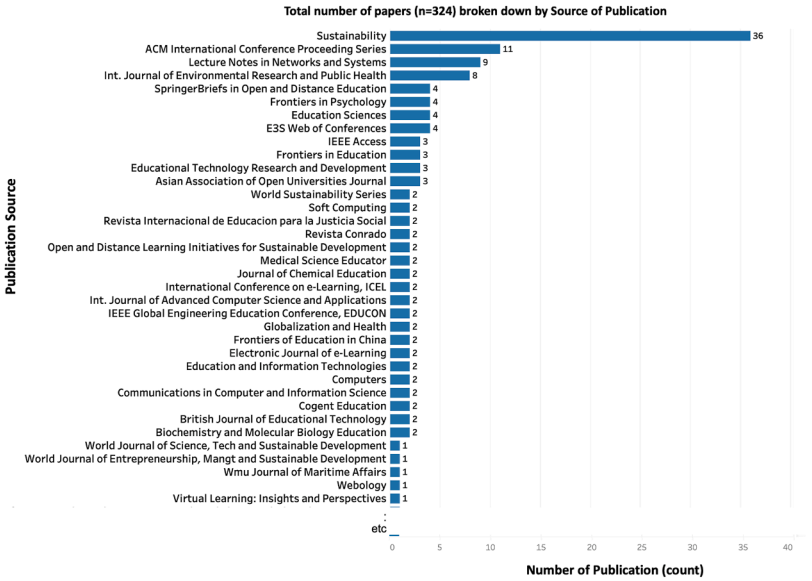


Fig. 4. Studies in use of digital technology in education (n = 324) broken down by publication source.

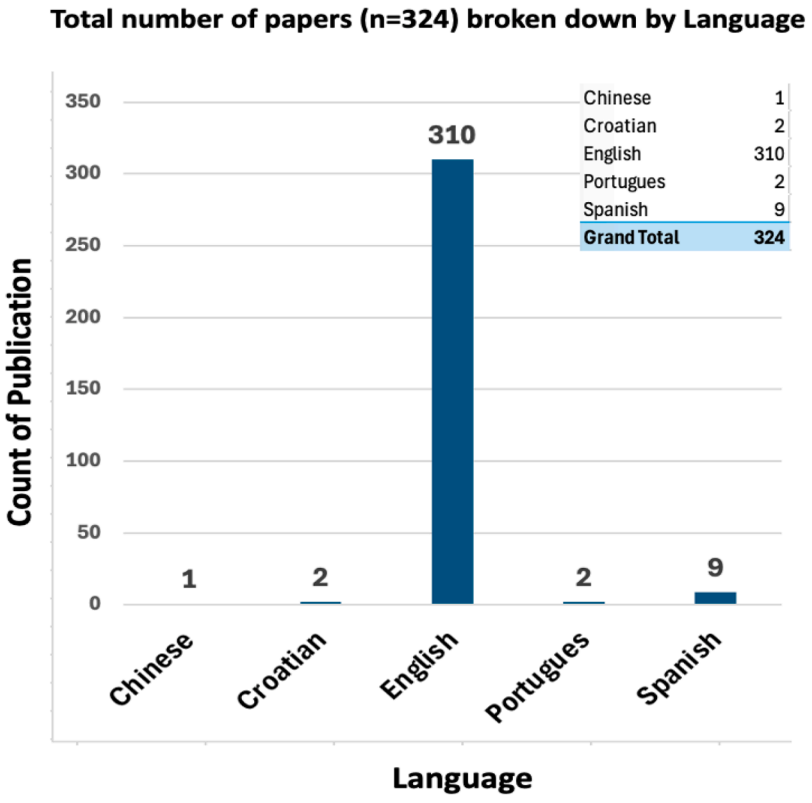


Fig. 5. Selected papers (n = 324) broken down by main language for publication.

a clear interrelation between key terms like “Post-Covid education”, "Information technology," "High quality education," and "Sustainable development goal". Terms such as "Access" (Fig. 7) appears as a critical term linked to digital adoption, and emphasizing the existing disparities in technology availability across regions, that was inadvertently accentuated by the recent global pandemic, especially in the rural regions, as also found in the results of this study and our review of the available literature [3,10,11,14,25,141,163,197]. As a common denominator, this is an indicator that one of the main challenges to the use of digital technologies in education is the issue of “digital divide” which has remained a threat to effective adoption and implementation of the digitalized-education, particularly in the remote areas (see Sections 2 and 5) [10,25]. Socio-technically, this problem have not only been accentuated by the recent global pandemic (COVID-19) [3,10,22,23], but has also on the other hand, been related to the indigenous communities or institutions in the rural areas who had experienced limited or lack of access to the learning technologies or digital (education) platforms [10,14,15,102,198,199], which are discussed in detail in the Discussion (Section 5). Interestingly, the exponential rise in publications during and after the pandemic (see Fig. 2) may reflect growing global

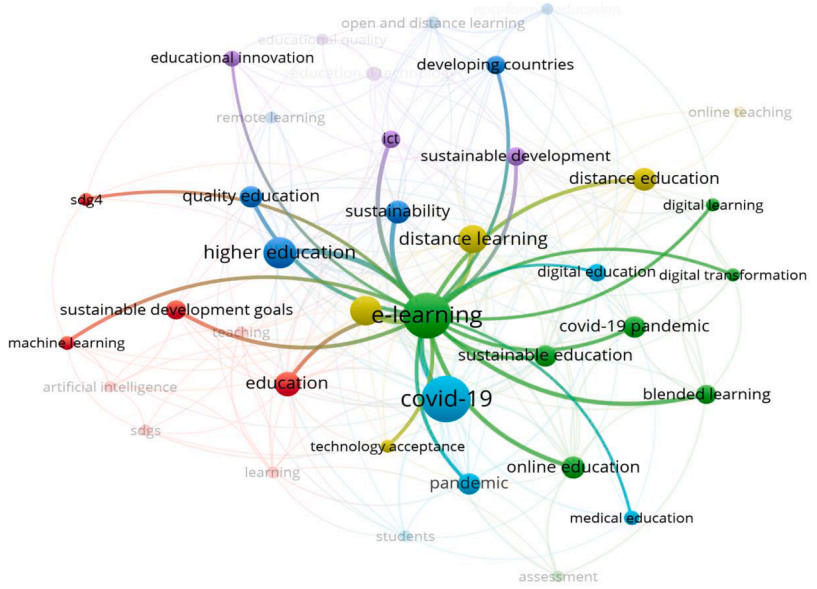


Fig. 6. Concept map and network analysis for Authors' keywords for the selected studies (n = 324).

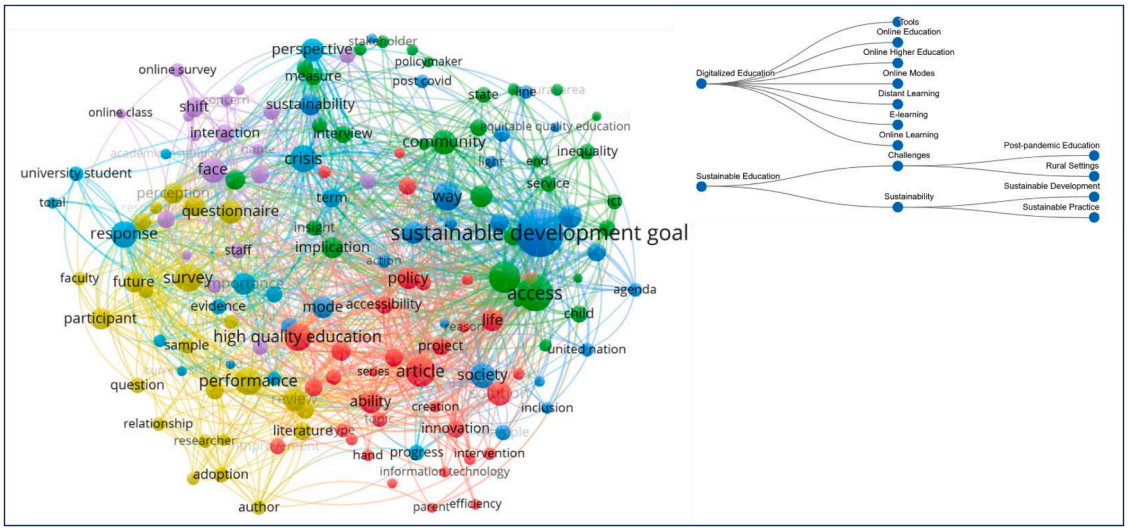


Fig. 7. Concept map and network analysis of text of the Title and Abstract of studies (n = 324).

attention to digital education as a solution and a challenge [3,11,163].

Consequentially, from the resultant Concept maps (illustrated in Figs. 6 and 7), we performed a comparison among the studies focus and key search terms: COVID-19, Rural education, and Sustainable development, respectively. This was done to identify the top terms and relationships between the keywords used in the research, and their underlying implications by explicitly linking the study's objectives to the thematic components (digital technology, COVID-19, rural education development, and SDG4), vice and versa. The results are presented and discussed in detail in Figs 8A and 8B, respectively.

Figs. 8A and 8B are Concept map and visualizations of the term frequencies and occurrences derived from the Author keywords (Fig. 8A) and the Title and Abstracts (Fig. 8B) of the analyzed papers (n = 324), by considering the individual studies' focus: rural education, COVID-19, and sustainability.

- Considering the Author keyword Network analysis and their interconnections (Fig. 8A); we note that the most prominent keywords are "COVID-19″ (75 occurrences) and "e-learning" (72 occurrences), followed by "online learning" (31 occurrences) and "distance learning" (26 occurrences). These terms were central to the network of the authors keywords across the data (Fig. 8A), indicating a strong focus on the role of online education during the pandemic and/or COVID-19's relevance to digital transformation in education [22,58,200,201]. The links between "COVID-19" with terms such as "pandemic", "sustainable education", "developing countries" and "sustainable development goals (SDGs)" (Fig. 8A) emphasizes the challenges of achieving sustainability during the pandemic or post-pandemic education [100,101].
- On the other hand, considering the term frequency and occurrences from the Titles and Abstracts of the analyzed studies (Fig. 8B), dominant themes and terms like "COVID" (237 occurrences), "pandemic" (187 occurrences), "challenge" (115 occurrences), and "development" (113 occurrences) are heavily represented. These terms higlights the challenges posed by the pandemic on education systems worldwide, particularly in the (infrastructure-limited) marginalized or low-tech regions [114,134,202,203]. Likewise, words like "sustainable development goal" (87 occurrences) and

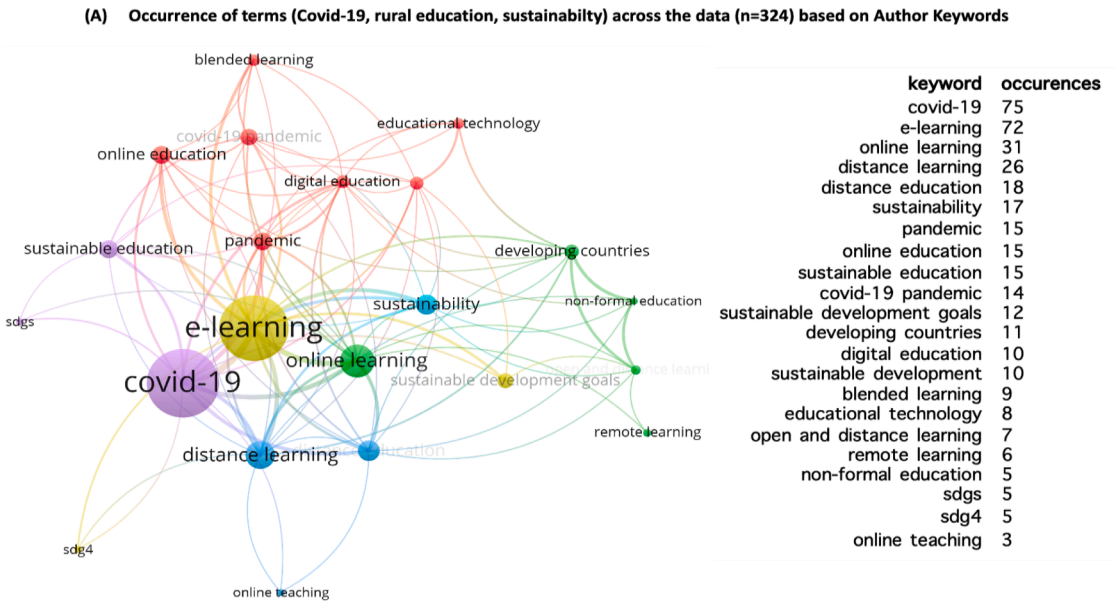


Fig. 8A. Frequency of top terms used in the data (n = 324) based on the Author keywords.

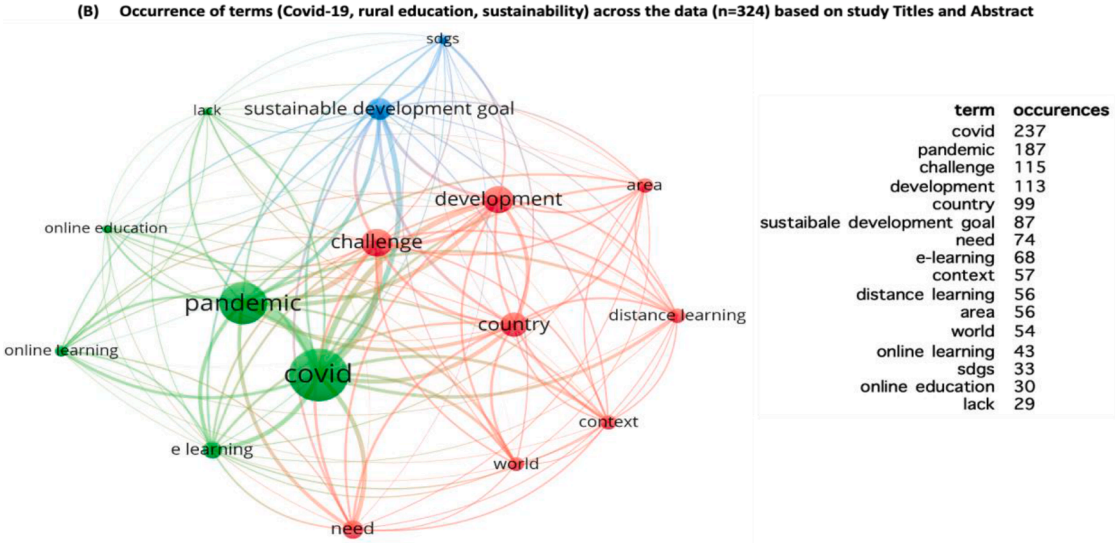


Fig. 8B. Frequency of top terms used in the data (n = 324) based on the studies Title and Abstracts.

"sustainability" (frequently appearing in the clusters) highlight a focus on long-term educational objectives in line with the global sustainability goals [170,204]. Whereas terms like "country" (99 occurrences) and "area" (56 occurrences) (see Fig. b) indicate a focus on regional and rural education development [27,58,74,144,205].

In summary, insights from the Network and thematic analysis (Figs. 8A and 8B) highlights the impact of COVID-19 on Education, globally [3,15,132,167,201,206–208]. The pandemic has accelerated the adoption of digital learning tools, transforming traditional education systems, worldwide [8,24,126]. However, it (COVID-19) has also highlighted disparities in access to technology, particularly in the rural and underdeveloped regions [10,11,14,25,141,163,197]. Emphasis on "sustainable practices" include the integration of digital tools into education, which has opened new pathways for promoting sustainable education, especially in the rural areas, aligned with the SDG 4 (quality education) goals and targets [51,55,170,204]. Challenges with digitalized-education in the developing countries is particularly highlighted (see Figs. 8A and 8B). For example, the prominence of terms like "developing countries" and "non-formal education" indicates barriers such as lack of infrastructure and skilled training for the educators [70,88,209,210]. Teachers and students should receive targeted training on the use of digital platforms to ensure effective use and delivery of (digital) education [49,70,211,212]. Strengthening of infrastructural development in the rural areas is also of critical importance. For instance, investment in internet access and digital devices for the rural and underdeveloped areas is essential to bridge the digital divide [10,11,82,163,165]. By addressing these challenges related to infrastructure, teacher training, and policy support, digital learning can play a critical role in achieving the sustainable educational goals, worldwide [40,50,55,129,170,213–216].

4.6. *Sentiment analysis of selected studies Abstract (n = 324)*

The authors implemented Sentiment Analysis, a type of Text mining technique [217,218–221], to analyze the Abstracts of the selected

studies ($n = 324$). This was done in order to determine how the different terms contained in the text of the studies are used to express emotions, and how those may differ based on the analyzed study periods, i.e., Pre-Covid (2017–2021), During-Covid (2020–2021), and Post-Covid (2022–2023). The sentiment or emotional valence (EV) analysis [118,218,222,223] evaluates and quantifies the emotional impact of experiences, interactions, or stimuli by assessing the intrinsic attractiveness or aversiveness of the terms (intensity of words or term quantification, often referred to as polarization) extracted from datasets (e.g., events or stimuli). The polarity of these emotions are typically classified into Positive (+) valence, Negative (-) valence, or Neutral (0) valence (neither positive nor negative) [223–225]. The concept of emotional valence and its application have been widely explored, e.g., in educational research domain [117,118,218,223], as similarly applied in this study.

The sentiment analysis method in this study was implemented in R statistics software [122]. The method focused on obtaining through polarization (textual data quantification) [117,218,219,223,224], the valence scores or intensities of the terms used in the analyzed studies, which can be used to express an emotion (see Figs. 9 and 10). This process is achieved through the program summing up the average scores of the different terms in the text, represented as either positive (+), neutral (0), or negative (-) values, where the values with positive valence (+) scores represent attractive emotions, the negative (-) scores represents aversive emotions, and the zeros (0) represent emotions classified as neutral [218,219]. The results of the method are reported and discussed in Figs. 9 and 10, and Table 3.

In the results presented in Table 3 and Fig. 9, it can be observed that the large proportion of emotional valence (EV) score expressed by the different studies are classified as positive (+). This may be an indication of how attractive or impactful the majority of the studies have found the use of the digital technologies in education, particularly in the rural context and development, with maximum score of 38 (max=38.00) which was recorded during the COVID-19 (2017–2019) and min = −1.00 observed for Post-Covid (2022–2023). This result can be expected as it depicts how appreciative the users of the different innovative digital learning technologies and resources, e.g., the UNESCO's National Learning Platform and Tools [48], have found it (digital technologies) to be. Moreover, the negative sentiments, e.g., post-COVID (Fig. 9) may reflect concerns about "digital divide" challenges and equitable access to digital tools [10,11,77,88]. To explain the following phenomenon (Fig. 9 and Table 3), it can be said that while the innovative tools and technologies were used to fosters education for the learners, particularly at the peak of the pandemic, and were used to ensure access for the marginalized users in the developing regions, anytime, anywhere, and at any place, etc. However, it is noteworthy to mention that the negative (−1.00) valence score that was also observed for Post-Covid (see Table 3, Fig. 6(C)) may be attributed to how concerned the users may be in anticipation to access to the digital learning tools and platforms, as confirmed in the results (Table 3 and Figs. 6-9) and our review of the available literature (Section 2), that purportedly highlights the "digital divide" as the main challenge to the wide adoption of digital technologies in education, particularly in the remote regions [3,10,45].

In our final analysis (Fig. 10), the authors explored the different categories or classification of emotions expressed by the selected studies ($n = 324$) in the Abstract, and how those may differ based on the study periods (i.e., Pre-Covid, During Covid, and Post-Covid). The authors note that the classification of the emotions' categories and its application within the educational domain has been defined in the existing literature [118,218–223,226]. In this study, the theoretical and practical implications of such type of analysis is gained by making use of the extracted information (textual data) to draw meaningful insights in connection with the research topic and objectives. Consequentially, in Fig. 10, the study adopted the emotions classification of the educational-related datasets defined in Litman and Forbes-Riley [218] and Okoye et al. [219] to classify the category of the different emotions expressed in the Abstracts of the analyzed studies ($n = 324$).

In Fig. 10, it can be said that while the majority of the analyzed

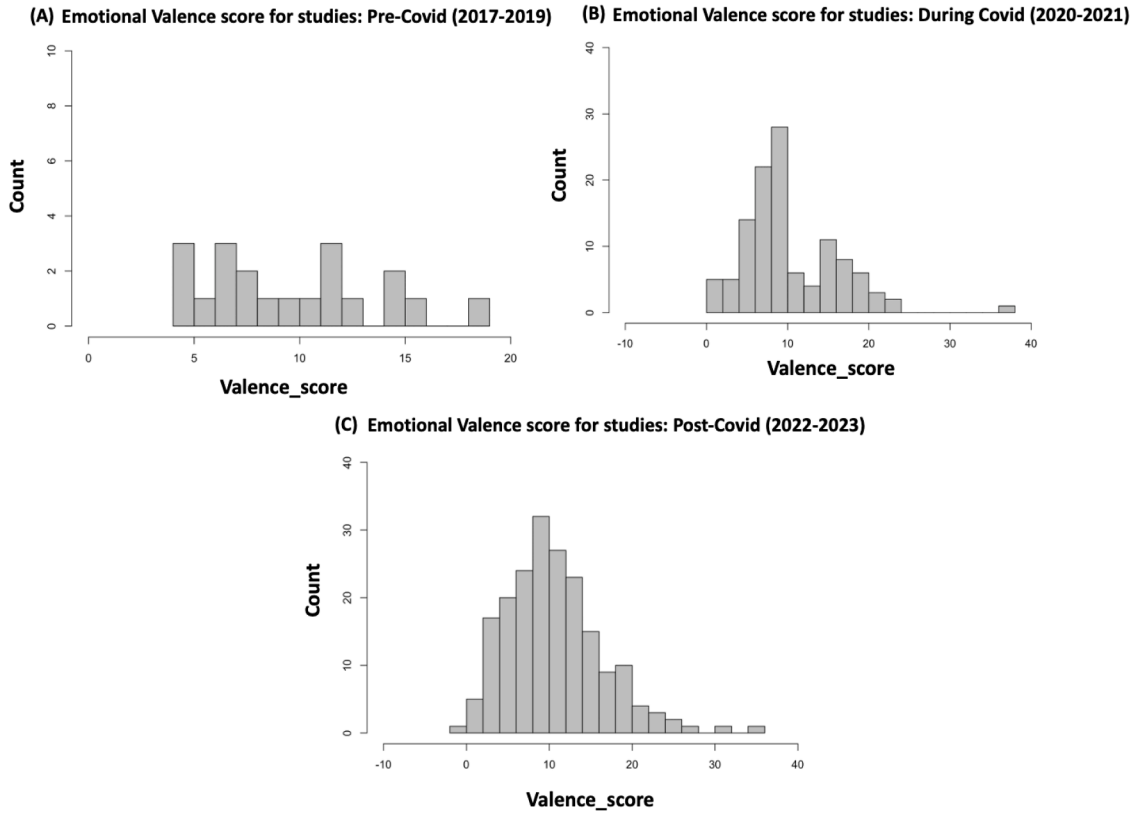


Fig. 9. Emotional valence (EV) of Abstract of the analyzed studies ($n = 324$) broken down by the study periods.

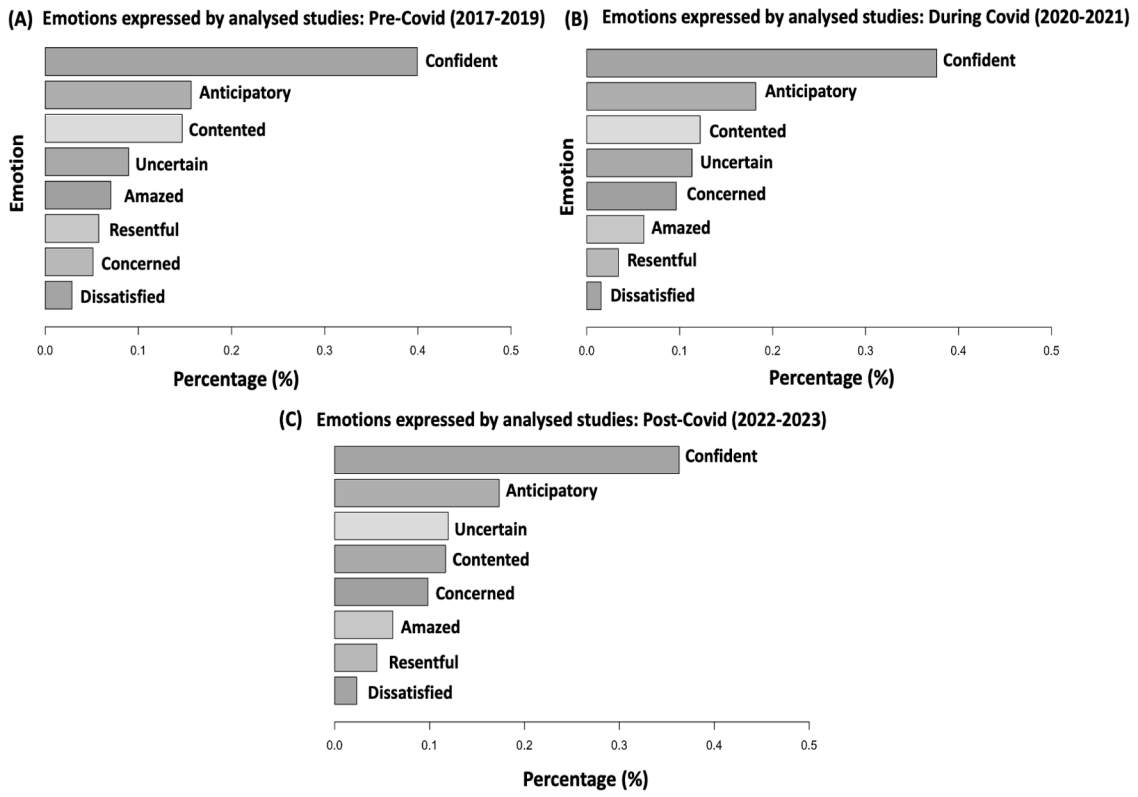


Fig. 10. Emotions category (classification) found in Abstract of the studies ($n = 324$) broken down by the study periods.

Table 3
Summary of EV score of Abstracts of the analyzed studies ($n = 324$) broken down by the study period.

Study period	min	median	mean	max
Pre-COVID (2017–2019)	4.00	9.50	9.95	19.00
During-COVID (2020–2021)	0.00	10.00	10.78	38.00
Post-COVID (2022–2023)	−1.00	10.00	11.07	35.00

Note: min = −1.00, max = 38.00.

studies trust (confident) that the use of digital technologies has a huge impact (highly significant) in fostering education, particularly in the remote regions. On the other hand, they are equally "anticipatory", perhaps, due to the many associated challenges and implications of the use of the digital technologies for learning to practice [3,52,77,79,154,227]. For example, the Anticipatory emotions (Fig. 10), especially post-pandemic, highlights a growing awareness of unresolved issues like infrastructure gaps and the need for sustainable solutions in education systems [12,14,17,70,178].

Furthermore, it is interesting to mention the fact that prior to the recent global pandemic (pre-Covid) (Fig. 10A) that the studies were less "concerned" about the impact and implications of the use of the digital technologies in education compared to during-Covid and post-Covid (see Fig. 10B and C), therein the studies were becoming more concerned (Fig. 10B and C). Apparently, this result could be expected as there is currently evidence in the amount of growth or increase in researcher's interest in the topic in recent years [45,102,174]. Moreover, this is also a justification of the exponential increase in publications, particularly during the Post-Covid (see Fig. 2) that the study have found in this topic.

Several factors may contribute to these findings above. First, the various contingency plans and alternative learning options (due to swift shift to the remote learning) by the several institutions may have made the users (teachers, students, educators) not only appreciative of the continuity of the teaching and learning processes [8,207,228]. But, on the other hand, may also have triggered the users' concern, uncertainty, and more or less dissatisfaction with the learning loss or voids (e.g., lack or limited access to the learning tools and platform, loss of face-to-face interactions, etc.) presented by the rapid shift to remote mode of learning, particularly for those in the rural or indigenous learning settings [7,10,15,24,33,53,67,69,82,134,137,199,206,229,230].

5. Discussion

The outcome of this review (see Section 4) indicates that *digital technologies* is becoming an integral and indispensable part of the modern-day education (digitalized-education). However, in the rural and resource-limited context, the prospects of effectively and sustainably implementing the "digitized-education" tends to be characterized by low technological infrastructure, e.g., lack or limited access to computer technology, or the so-called "digital divide" per se [10,15,199].

It is interesting to mention how at the time of this study and in a short frame of time, the plethora of studies that emerged or investigated the impact of the digital technologies in education, particularly as aftermath of the recent pandemic or post-pandemic education (see Fig. 2). This could owe to the fact that the ripple effect of the pandemic in education is currently becoming a contemporary topic being addressed by the researchers, educators, government parastatals, and policy makers [1,2,23,24,40,45,51–53,55–67,102]. It shows the significant increase in COVID-19 related research (Fig. 2) that, in turn, underlines the different efforts put by the researchers to uncover the impact of the shift from the traditional models of learning (face-to-face) to the remote or online learning/education [84,231,232].

Presently, educators, researchers, and many institutions are faced with the task of documenting the respective challenges that have spanned, or the lessons they learned as a result of the COVID-19 pandemic [67,83,132,233]. The educators and policymakers alike, are forced to act and adopt several turn-around policies and educational

innovations that can fit into their different educational systems or settings in anticipation to the post-pandemic education era [1,55,56,79,132]. The said *educational innovations* in the way learning is being delivered (e.g., digitized-education) is further accentuated or will be most challenging for the users (educators and learners) in the remote areas or geographical dispositions [3,11,14]. Therefore, effective educational plans in such regions (low-tech or resource-limited) would necessary include (i) managing learning continuity, and (ii) ways for improvement/acceleration of the digitalized-education [1,2,55,56,75], while also ensuring that education is made more inclusive, effective, and resilient than it was before, e.g., pre-COVID-19 [1,2,50,51,54–57,75,76,138,216].

In these perspectives, infrastructural development and investment in educational technologies is also of utmost importance. Governments and institutions should prioritize investments in digital infrastructure, such as broadband access and affordable devices, particularly in the rural and underdeveloped areas [12,60,103,128,138,158,159]. Collaborative public-private partnerships can bridge infrastructure gaps [234,235]. Professional development programs should be established to enhance digital literacy among teachers and students by focusing on effective use of educational technologies [5,70,174,236]. Tailored learning tools can address the needs of diverse student populations, especially those within the rural settings [48,237]. Scalable low-tech solutions such as the UNESCO's National Learning Platform [48] should also be emulated and explored for areas with limited technological infrastructure, to ensure equitable education access, and address to a greater extent, the problem of "digital divide" in education, from a global perspective [11,14,40,48]. These steps can create actionable pathways for stakeholders to address the digital education disparities and promote sustainable development goals in education, worldwide [2,11,163,170,171,238].

Considering the sustainable integration, and planetary development and practices -wise, the findings of this study (see Section 4) align with the SDGs (see Table 4), e.g., SDG4 (Quality Education) and SDG10 (Reduced Inequalities) by advocating for a holistic and inclusive approach to technology-enhanced education, especially in the rural or low-tech regions [3,11,14,163,197]. By evaluating the impact of this current review and study to global educational research, we note that the results and outcome of this study (see Table 4) is in direct triangulation with four of the global sustainable development goals (SDGs) [26], namely: SD4 – that promotes quality of education [170], SDG10 – that addresses reduced inequalities [171], SDG11 – that promotes sustainable cities and communities [239], and SDG17 – that promotes partnerships for the goals [237]. These SDGs cover the speculations that inclines the several countries (both low- middle- and high- income) to promote prosperity and innovative strategies that aim to build economic growth and address the range of social needs, including quality of education for all [240]. Along these lines, the issues, challenges, and improvement strategies presented in Table 4, provides a critical outline and framework, not just for the much-needed COVID-19 recovery or post-pandemic education, particularly in the remote or resource-limited regions. But also, as an incentive for further research and actions plans by the concerned stakeholders (educational institutions, governments, policymakers, financial investors, etc.) toward a worldwide effective and equitable adoption of the digital technologies within the educational ecosystem [53–57,67,77].

5.1. Theoretical and practical implications of this study

Digital divide has remained a major barrier or obstacle to the wide adoption of "digitalized-education" especially in the remote regions or settings. In line with the SDG goals and targets (Table 4), those in the rural or low-tech regions are still facing a startling challenge in fully gaining the vast benefits of the digitized-education [3,10,15,199]. The recent global pandemic has placed the promising impact of the new and emerging educational technologies and innovations in the spotlight [40,51,55,56,75,77,129,216,243–245].

Table 4
SDGs' dimensions, issues and challenges, and improvement/heightening strategies.

SDG Dimension	Issues/challenges	Improvement/heightening strategies
SDG4: Quality Education	Lack of digital infrastructures and networks Lack of digital literacy and skills Digital divide Slowness in digital transformation [3,54,57,87,161,209,215,227].	Massive investment in digital technologies in education Need and potentiality of improving the teachers' and students' digital literacy skills Enhancing educators' professional development and practices Reforming instructional methods Production of customized software and courseware
SDG10: Reduced Inequalities	Digital divideInequalities amongst students and staffsEducation system that is economically correlated with incomeunequal distribution of responsibilities, e.g. ascribed to women (gender inequality – SDG5) [3,229,233,241,242].	Provision of digital infrastructures, network, and access to disadvantaged groups Promotion of Education-for-All irrespective of social, economic, and linguistic background
SDG11: Sustainable Cities and Communities	The need to support positive economic, social, and environmental links between urban, peri-urban, and rural areas by strengthening national and regional development planning such as digitalized-education and online learning resources and network [28].	The adoption of digital technologies in higher education as a tool to create social links between rural and urban areas (more universities exist in urban areas, and people from rural areas could attend those universities through online learning)
SDG17: Partnerships for the Goals	Challenges for educators, researchers, government, policy makers, and society that has to do with promoting innovative practices and collaborative plans for accelerating digital transformation, literacy, and skills for the stakeholders [24,40,51,56,57,76,77,227].	Global Education initiatives, coalition, and partnerships amongst the different stakeholders, that aim to promote coordinated and innovative actions to unlock educational-related solutions for the teachers and students. Long-term educational recovery and coping strategies by the educators, particularly in lieu of aftermath of the recent Covid-19 pandemic (Post-Covid Education), with a principle focus on inclusion and equity.

While a large proportion of the learners' population across the globe are fully back in school from disruptions caused by the pandemic [137,246,247], it is hoped that the *digital technology* can foster the human-centered recovery for them (teachers, students, educational community) [53,54,57,137,138]. According to the recent report by UNESCO [50], *digital technologies* can introduce agile ways of delivering education and achieve a "large-scale educational ecosystem" that promotes life-long learning [248,249]. The World Bank [1,2] has also provided strategies and action plans in understanding the loses (learning poverty) due to the recent pandemic by looking for ways to *scalable* and *sustainably* operationalize the use of digital technologies in education. These strategies are projected under five main themes: (i) asking why e.g. learning loss/poverty, (ii) designing educational technologies for scale, (iii) empower the teachers, (iv) engage the educational ecosystem, and (v) provision of data-driven educational models or approaches [2,102]. An inclusive access to the new and emerging technologies is critical to achieving the quality of education or the SDG goals and target

(see Table 4) [50,76,77]. The stakeholders, particularly educators in the remote regions, must commit to responding to the post-COVID education, and the linked didactical and social requirements, by building resilience and reimagining education to leave no one behind [19,50,56,77].

However, despite the several challenges posed by the COVID-19 pandemic, we must, on the other hand, acknowledge the fact that the different educational organizations and institutions of learning have been working together to improve the quality of education for millions of the teachers and students across the globe [51,54,56,57,75–77,250]. Those initiatives has ranged from provision of blended pedagogies [24,230] and digital skill development for the teachers especially in the low-tech settings or regions [3,14,15,123,199,251,252], to flexible curriculum and adequate training and digital skills and competencies to prepare the students for the most in demand (digital) jobs and learning circumstances of today, or perhaps, what is called the "digitally-savvy generation", at large [50,56,215,249,253].

Current scientific evidence has shown that the (educational) practice of "digitalization" and "datafication" are reshaping the way learning is being delivered across the many higher institutions of learning, and are simultaneously being pioneered by different intergovernmental and educational organizations, such as the OECD [54], World Bank [2,254], and UNESCO [40,48]. Through the massive increase in the use and application of the educational technologies, it can be said that the COVID-19 have stretched the process of "digitalization in education" [255–257]. This transformation will eventually cater for the problem of "digital divide" – see Table 4 [3,10], highlighted in this review study. The several lines of actions are envisioned to range from prioritizing free and early childhood education, e.g., through equitable investment in education for all [18,77], to encouraging the stakeholders or Member states to continue to provide advice, training, tools, and infrastructure at no or low cost for those who need it in education [48,50,77,243], particularly those in the indigenous or low-tech regions [10,15,199], and as an aftermath of the COVID-19 pandemic (post-pandemic education) [50,138,258].

In terms of "Building Capacity for ICT and Open Education" particularly in the post-pandemic era, it is noteworthy to mention that the UNESCO's Institute for Information Technologies in Education (IITE) [128] have stated that "the wide adoption/development of digital technologies and their penetration into the education system has the capability to open up new opportunities for the teachers, students, and educators" especially in the rural areas or regions [18,77]. The new (digital) educational opportunities include to name but a few: (i) increase in accessibility of education and students' involvement and engagement in the learning processes, worldwide, (ii) enhancement of students' motivation and interest to learn, (iii) inclusiveness and personalization of learning, (iv) significant reduction in the bureaucratic and didactic burden on teachers, and (v) increasing the efficiency and transparency of the educational management systems. The report by IITE [128] suggests an integrated approach to rethinking, redesigning, and reimagining the activities of the several educational organizations to include "innovative technological solutions" as one of the pertinent/effective ways to attaining the much-needed "technological transformations" for quality, equitable, and inclusive education [9,11,51,56,76,77].

Policy -wise, a "continuous and accelerated learning in response to the post-pandemic era" is needed. For example, initiatives such as the Global Partnerships for Education (GPE) [160] and the UNESCO's National Learning Platform and Tools [48] has proved effective. This includes to name but a few educational initiatives that aim to promote: Development of blended learning options for the students, Use of LMS (learning management systems) as central platform for teaching, learning, communication, advice, and support, EdTech for supporting remote and accelerated learning, Remote Formative Assessment solutions, Read@Home learning packages (books and OER materials) to massively engage the students and their parents at home, Compendium of Lesson plans and tools to improve reading instructions, and Technology for Teaching (T4T) by identifying scalable low-and-high-tech or even no-tech solutions for teachers' professional development [2,24,48,259].

Socio-technical and pedagogical -wise, the aforementioned (digital) solutions are perceived as promising ways of handling the "digital (learning) divide" that have inadvertently spanned across the marginalized or low-tech countries, and particularly accentuated due to the after (ripple) effect of the recent global pandemic in education [3,10,14,15,199]. The ongoing challenges with infrastructure and access to digital platforms and resources continue to impede rural areas from fully embracing and gaining the vast benefits of digital education. This is evident from the prominence of keywords like "access" in the Network analysis and Sentiment concerns we observed in Sections 4.5 and 4.6 for the analyzed studies, especially in the context of post-pandemic education (see Figs. 7 and 10).

To summarize the theoretical and practical contribution of this systematic review; it can be said that the "impact or challenges with the digitalized-education upon sustainable education and practices, particularly in the rural or resource-limited settings and the COVID-19 pandemic factors" has been a subject of growing interest. The reviewed publications in this study ($n = 324$) helped to provide scientific evidence and invaluable information on the challenges faced by the stakeholders (educators, teachers, students, educational society) in the different contexts. The need for development of sustainable online-based educational models, and the specific struggles of the stakeholders in the rural areas or regions were also highlighted. Emphasizes on the importance of addressing the *digital divide* or *digital learning inequality*, and providing a comprehensive support for educators particularly in the rural development context, and as an aftermath of the post-pandemic education, formed the main contribution of this study.

Actionable recommendations based on the outcome of this current review include:

- Diverse perspectives: Future studies can consider including studies from various geographic regions or individual country-specifics to understand global variations in digitalized-education practices and the rural development impacts.
- Focus on equity: Works addressing the *digital divide* and its implications for rural education development and sustainability should be encouraged.
- Integration of sustainable practices: Actionable recommendations and pedagogy development, such as policy guidelines for rural digital education initiatives post-pandemic, should be implemented.
- Technology analysis: Promote analysis of specific digital tools and their effectiveness in promoting sustainable education and practices: during vs after the pandemic.
- Cross-disciplinary studies: Include interdisciplinary studies bridging technology, education, and sustainability for a holistic or conceptual overview of the topic.

Looking forward, a snippet of the summary of the main insights from the relevant literatures in this topic, which can be used to drive educational policies and sustainable educational practice, are as follows:

- The transition to digital learning during the pandemic has posed challenges for educators and students, especially those from poor and rural backgrounds [114].
- A sustainable online-based educational model, including online platforms, assessment systems, and digital literacy, has been projected to help facilitate the digitized-education [186].
- The digital divide has intensified in vulnerable areas, leading to limited digital literacy levels and restricted access due to the technological and economic gaps [260].

- Teachers in rural areas have encountered challenges in digital learning, including unequal student access to technology, thereby, leading to digital learning inequality [72].
- The COVID-19 pandemic has emphasized the need for higher education institutions to embrace digitalization for a sustainable and continuous learning approach, with a focus on multifaceted approaches to address the challenges posed by the pandemic [261].
- The pandemic has led to a rapid digital transition in higher education, therefore, highlighting the importance of integrating technology into professional education and addressing the challenges and opportunities for growth and innovation [100].
- The pandemic has also brought attention of the educators to specific struggles of the teachers and students particularly in the rural regions, e.g., leading to an increase in rural teacher/student attrition and the need for comprehensive support for them especially in the post-pandemic era [61].

Effects of Pre-, Intra-, and Post-Pandemic Education on Digitalization of Education in Rural Settings and Development:

- The COVID-19 outbreak caused disruption of learning activities and a shift towards online education, posing challenges for educators and students, particularly those from low-tech settings or backgrounds [114].
- The pandemic has deepened the existing *digital divide* and socio-economic inequalities, particularly in rural and resource-limited areas, due to unequal access to digital infrastructure and technology [141].
- The impact of the pandemic control measures on student' education in rural areas has led to an increase in rural teacher attrition, posing challenges for educational excellence and school culture [61].
- The pandemic has forced schools and educational institutions to adapt to new modes and models of teaching and learning, including online and remote learning, affecting curriculum, assessment, and pedagogy [101].

Best practices for integrating the digitalized-education in rural settings to promote sustainable education can be adapted/adopted. This includes:

- The integration of technology and digital resources in rural schools can contribute to reducing isolation by promoting inclusive education, and improving opportunities in rural territories [58].
- Digital resources adapted to multigrade classrooms and experiences related to blended learning environments have been developed, therefore, capable of enhancing educational achievements in rural territories [58].
- The Holistic Education and Digital Learning (HEDL) model, including digital learning applications, has significantly elevated literacy and language skills in rural contexts [204].
- Digital platforms have the potential to contribute to the sustainable development of rural areas and increase employment of the rural population through the digitalization of physically existing classroom objects, and the institutional environments [262].
- Challenges in implementing digitalized-education in rural/underdeveloped areas must include efforts in effective application of digital education resources, teacher training, and creating a positive professional learning atmosphere [172].
- Policymakers, professional leaders, educators, and parents need to take collective actions to create a more effective online educational environment for students, especially from the vulnerable and disadvantaged groups in rural areas [263].

To summarize the key lessons learned and main finding of this review; we note that it is important to address the challenges of the *digital divide* and ensure inclusive and equitable *access* to the digital resources and education, particularly in the rural areas or resource-limited settings. The international or global educational initiatives and organizations such as UNESCO [40,55,56] have emphasized that never before has the educational system witnessed disruption at a large scale, and partnership amongst the several stakeholders is the only way forward [55]. In those directives, UNESCO have called for "coordinated" and "innovative" actions aimed to unlock solutions that purportedly supports the teachers and students with the teaching-learning processes, especially through "technological interventions". The different stakeholders (educators, governments, policymakers, funders) are invited to not only focus on (technological) solutions that ensure the users' recovery as per the pandemic (post-pandemic education), but also with a principle focus on inclusion and equity in the longer term [40,55]. Idiosyncratically, those actionable plans and efforts must be designed and implemented to ensure that the teachers and students, particularly those in the low-tech or rural areas, have access to adequate digital tools and literacy, computer technologies, and network infrastructures to ensure an equitable, scalable, and sustainable education, worldwide [15,82,161,198,227].

It is important to mention, on the other hand, that some of the developing regions and economies are making efforts to bridge the so-called "digital gap". For example, some developing regions has provided conceptual framework and SWOT analysis for its Member states to harness digital technologies and innovations in transformation of the societies and economies [55,70,75,89,264]. Those digital strategies are designed particularly to promote digital integration, generate inclusive economic growth, break the digital divide, promote public-private partnerships, and eradicate (learning) poverty for the socio-economic and pedagogical development and ownership of modern tools and technologies [55,70,75,89,264]. Indeed, the main objectives and components of the stated strategies include: To build a secured digital system, Expand access to open, interoperable, reliable, and secure internet, Expand access to and adoption of key enabling digital technologies, platforms, and services, Facilitate investment and partnerships in digital economy and ecosystem, Enable the coherence of existing and future digital policies and strategies at both regional and national levels and mobilize effective cooperation between institutions, and Promote open standards and interoperability for cross-border trust framework, personal data protection and privacy at large [55,70,75,89,264].

Along these lines, the scientific impact and relevance of this current review study is summarized as follows:

- It offers a valuable contribution to understanding the pedagogical impact of digital technologies in education, using the PRISMA methodology for systematic reviews to assess barriers and opportunities to effective adoption of the digitalized-education in the various contexts (COVID-19 and Rural Education Development). By examining n=324 studies published between 2017 and 2023, it provides a comprehensive overview of the challenges and opportunities related to *digitalized-education* both pre-, intra-, and post-pandemic, with particular attention to rural education development [27,34,35,58,60,101].
- One of the most significant contribution and strengths of this research is its attention to the "digital divide" as a primary barrier, especially in remote regions where limited access to digital resources impedes effective educational outcomes. This insight addresses a crucial issue in contemporary education that has become even more relevant due to the recent pandemic. The study's focus and findings on *access* disparities highlights the need for sustainable, scalable solutions to bridge this (digital) gap, aligning well with the UN's Sustainable Development Goals (SDGs) for inclusive and equitable quality education and delivery (see Table 4) [3,10,11,25,26,163,170,238].
- The use of PRISMA methodology further enhances this current study's rigor by providing a structured approach to evaluating existing literature, ensuring a thorough and unbiased examination of

sources. Additionally, the study's findings and recommendations on "scalable practices for effective digital education" highlight practical implications that can inform policy decisions and support educational institutions in crafting more inclusive and resilient digital learning environments [24,58,102,104,106].

- Overall, considering the post-pandemic education and future prospects of this study, this paper is both timely and impactful by offering critical insights that are essential for understanding and addressing the challenges of digitalized-education, especially in underserved regions. The study's alignment with the global sustainable development goals (SDGs) adds to its relevance, making it an important contribution to the field of educational technology and pedagogy, worldwide [45,51,52,55,56,101,129,138,173,265–267].

5.2. Limitation and future directions for research

In this study, a systematic review and synthesis of publications in the use of digital technologies in education within the rural development and COVID-19 context is presented. However, the authors acknowledge that it may come with some limitations. The findings and recommendations by the authors are based on data we collected for a seven-year period (2017-2023) to cover research and publications done during the pre-, intra-, and post-COVID-19 periods and rural education development context. There could be potentially other themes or impounding factors (e.g., restrictions in databases, missing alternative keywords, or wider scope in number of database searched, etc) that may exist or emerge outside the studied period in the available literature, which may lead or systematically utilized to shed more light on the topic. Further data can be collected by future studies to cover a wider scope, database, alternative keywords, or timespan.

Furthermore, the authors triangulated the outcome of this study with the UN's SDG goals and targets, particularly as it concerns the use of digital technologies upon achieving the quality of education. While the study has pointed to some of the key indicators or factors that may serve as guideline for more robust future research in the topic or policy recommendation for the stakeholders; it is also important to mention that more research is needed to identify the individual countries' specifics or issues in the use of digital technologies in education by identifying the reach, barriers, and bottlenecks to the wide adoption of the digitalized-education in the diverse countries and hemisphere. For example, language bias or barrier could be one of the limitations. We found that approximately 95.7 % of the total reviewed articles were published in English compared to other languages. This can pose challenges for the non-English speaking stakeholders (researchers, teachers, students, educational institutions, government agencies, policymakers) that mostly dominate the rural contexts or resource-limited regions, which may in turn, result in underrepresentation of localized educational practices, challenges in digitalized-education, or underrepresentation of countries in the developing or resource-constrained regions.

Lastly, the authors note that the Text mining method we performed to understand the polarity or emotional valence (EV) scores of the analyzed studies, represents as an innovative method for conducting systematic review and meta-analysis of existing studies or educational dataset, and to the best of our knowledge, there could be few to no studies in the literature that have applied the method for meta-analysis or systematic reviews. Consequentially, this study serves as a methodological roadmap for future and further research andreviews to come that adopts the same *data-structure* approach.

6. Conclusion

This review identified the pedagogical impact and opportunities to the use of digital technologies in education. It used the PRISMA methodology to explore the available literatures by identifying the potential barriers, challenges, and opportunities to effective adoption of the digitalized-education, taking into account the pre-, intra-, and post-pandemic and rural education development factors. Covering a period of seven-years (2017–2023), it looked into the modest contributions of the selected studies ($n = 324$). The data analysis process include: trend examination, geographical and contextual diversity of the dataset, and thematic synthesis of the digital technologies' benefits, challenges, and implementation done in the context of COVID-19 and rural education development. This was done using methods such as Concept mapping and Text mining by leveraging data visualization and analytics tools such as: VOSviewer, Tableau, and R Statistics software. Consequently, it identified the "digital divide" as the main challenge to the effective adoption of digitalized-education and/or attainment of the quality of education and its delivery by the educators, particularly in the remote or underserved regions. In addition, the paper critically shed light on the main implications of the study's review findings upon a *scalable* and *sustainable* educational practices, including their alignment with the UN's global sustainable development goals (SDGs) that are directly in line with the quality of education, reduced inequalities, and development-oriented society, at large.

Originality and submission status

The authors confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere.

Funding

This research was funded by the host institution

Data and code availability

The code used for the Text mining analysis in this study is available from the corresponding author on reasonable request. The selected studies and dataset used in this review study is deposited in the following repository for further reference and potential future research studies: doi.org/10.6084/m9.figshare.28127813

CRediT authorship contribution statement

Kingsley Okoye: Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Esmeralda Campos:** Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Data curation, Conceptualization. **Amit Das:** Writing – original draft, Validation, Data curation, Conceptualization. **Varsha Chakraborty:** Validation, Investigation, Data curation. **Mahuya Ghosh:** Validation, Investigation, Data curation. **Amlan Chakrabarti:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Funding acquisition. **Samira Hosseini:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to acknowledge the technical and financial support of the Institute for Future of Education, Tecnologico de Monterrey, in the publication of this work.

Data availability

Data will be made available on request.

References

[1] World Bank, "The World Bank's education response to COVID-19 - overview as of December 2020.", 2020. Accessed: Nov. 07, 2021. [Online]. Available: https://thedocs.worldbank.org/en/doc/487971608326640355-0090022020/original/ExternalWBEDUResponsetoCOVIDDec15FINAL.pdf.

[2] World Bank, "Digital technologies in education | education and technology overview: development news, research, data.", 2021. Accessed: Dec. 02, 2021. [Online]. Available: https://www.worldbank.org/en/topic/edutech#2.

[3] M. Laufer, et al., Digital higher education: a divider or bridge builder? Leadership perspectives on edtech in a COVID-19 reality, Int. J. Educ. Technol. High. Educ. 18 (1) (2021) 1–17, https://doi.org/10.1186/S41239-021-00287-6, 2021 18:1.

[4] C. Mercader, J. Gairín, University teachers' perception of barriers to the use of digital technologies: the importance of the academic discipline, Int. J. Educ. Technol. High. Educ. 17 (1) (2020) 4, https://doi.org/10.1186/s41239-020-0182-x.

[5] R. Ramsden, R. Colbran, E. Christopher, M. Edwards, The role of digital technology in providing education, training, continuing professional development and support to the rural health workforce, Health Educ. (2021), https://doi.org/10.1108/HE-11-2020-0109.

[6] W. Bao, COVID-19 and online teaching in higher education: a case study of Peking University, Hum. Behav. Emerg. Technol. 2 (2) (2020) 113–115, https://doi.org/10.1002/hbe2.191.

[7] K. Ma, M. Chutiyami, Y. Zhang, S. Nicoll, Online teaching self-efficacy during COVID-19: changes, its associated factors and moderators, Educ. Inf. Technol. (2021) 1–23, https://doi.org/10.1007/s10639-021-10486-3 (Dordr).

[8] J.O. Woolliscroft, Innovation in Response to the COVID-19 Pandemic Crisis, Acad. Med. (2020), https://doi.org/10.1097/ACM.0000000000003402.

[9] D. O'Halloran, R. Opp, and V. Rastogi, "This platform can help policymakers increase digital inclusion | World Economic Forum - Tech for Good - Sustainable Development", 2021. Accessed: May 17, 2022. [Online]. Available: https://www.weforum.org/agenda/2021/12/platform-help-policymakers-increase-digital-inclusion/.

[10] C. O'Hagan, "Startling digital divides in distance learning emerge - UNESCO press service - global education coalition", 2020. Accessed: May 02, 2022. [Online]. Available: https://en.unesco.org/news/startling-digital-divides-distance-learning-emerge.

[11] D. O'Halloran, "Take the 1 Billion lives challenge to close the digital divide | World Economic Forum - Tech for Good - Digital Inclusion", 2021. Accessed: May 17, 2022. [Online]. Available: https://www.weforum.org/agenda/2021/09/take-the-1-billion-lives-challenge-to-close-the-digital-divide-edison-alliance-inclusion-internet-connectivity/.

[12] K. Okoye, J.T. Nganji, J. Escamilla, J.M. Fung, S. Hosseini, Impact of global government investment on education and research development: a comparative analysis and demystifying the science, technology, innovation, and education conundrum, Glob. Transit. 4 (2022) 11–27, https://doi.org/10.1016/J.GLT.2022.10.001.

[13] M. Gardiner, "Education in rural areas | Issues in education policy No. 4, Centre for Education Policy Development (CEPD)," 2008. Accessed: Aug. 14, 2022. [Online]. Available: https://genbase.iiep.unesco.org/applis/epidoc/notice27391.html.

[14] M. Martens, et al., Being on the wrong side of the digital divide': seeking technological interventions for education in Northeast Nigeria, ASLIB J. Inf. Manag. 72 (6) (2020) 963–978, https://doi.org/10.1108/AJIM-05-2020-0172.

[15] E. Sánchez-Cruz, A. Masinire, E.V. López, The impact of COVID-19 on education provision to indigenous people in Mexico, Rev. Adm. Pública 55 (1) (2021) 151–164, https://doi.org/10.1590/0034-761220200502.

[16] A.P. Aguilera-Hermida, A. Quiroga-Garza, S. Gómez-Mendoza, C.A.D. R. Villanueva, B.A. Alecchi, D. Avci, Comparison of students' use and acceptance of emergency online learning due to COVID-19 in the USA, Mexico, Peru, and Turkey, Educ. Inf. Technol. 2021 (2021) 1–23, https://doi.org/10.1007/S10639-021-10473-8.

[17] A. Awad, W. Al Ali, Removing barriers to quality education in the MENA region, Stanf. Soc. Innov. Rev. 2024 (2024), https://doi.org/10.48558/H9HZ-GY31.

[18] UNICEF, "Education | Working to ensure that all children in the region have equitable opportunities to quality and relevant education - UNICEF/UN036092/Mackenzie.", 2024. Accessed: Nov. 26, 2024. [Online]. Available: https://www.unicef.org/mena/education.

[19] UNESCO, "Berlin declaration on education for sustainable development | ED-2021/WS/18", p. 15, 2022. Accessed: Jun. 24, 2025. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000381229.

[20] UN, "Global call to invest in the futures of education: support the Paris declaration | Education within the 2030 agenda for sustainable development.", 2021. Accessed: Mar. 13, 2022. [Online]. Available: https://sdg4education2030.org/global-call-invest-futures-education-support-paris-declaration.

[21] F. Findler, N. Schönherr, R. Lozano, D. Reider, A. Martinuzzi, The impacts of higher education institutions on sustainable development: a review and conceptualization, Int. J. Sustain. High. Educ. 20 (1) (2019) 23–38, https://doi.org/10.1108/IJSHE-07-2017-0114/FULL/PDF.

[22] J. Crawford, et al., COVID-19: 20 countries' higher education intra-period digital pedagogy responses, J. Appl. Learn. Teach. 3 (1) (2020) 1–20, https://doi.org/10.37074/jalt.2020.3.1.7.

[23] R.M. Viner, et al., School closure and management practices during coronavirus outbreaks including COVID-19: a rapid systematic, review, 4, Elsevier B.V 4 (5) (2022) 397–404, https://doi.org/10.1016/S2352-4642(20)30095-X.

[24] K. Okoye, J.A. Rodriguez-Tort, J. Escamilla, S. Hosseini, Technology-mediated teaching and learning process: a conceptual study of educators' response amidst the Covid-19 pandemic, Educ. Inf. Technol. 26 (6) (2021) 7225–7257, https://doi.org/10.1007/s10639-021-10527-x (Dordr).

[25] M.M.P. Talandron-Felipe, The digital divide among students and support initiatives in the time of Covid-19, in: Proceedings of the ICCE - International Conference on Computers in Education, 2020, pp. 42–51. Proc.

[26] UN, "United Nations sustainable development – 17 goals to transform our world.", 2015. Accessed: Jun. 27, 2020. [Online]. Available: https://www.un.org/sustainabledevelopment/.

[27] UN, "Rural development | Department of Economic and Social Affairs.", 2021. Accessed: Nov. 30, 2021. [Online]. Available: https://sdgs.un.org/topics/rural-development.

[28] UN, "Goal 11 | Department of Economic and Social Affairs", 2021. Accessed: Nov. 30, 2021. [Online]. Available: https://sdgs.un.org/goals/goal11.

[29] UN, "Goal 8 | Department of Economic and Social Affairs", 2021. Accessed: Nov. 30, 2021. [Online]. Available: https://sdgs.un.org/goals/goal8.

[30] UN, "Goal 7 | Department of Economic and Social Affairs", 2021. Accessed: Nov. 30, 2021. [Online]. Available: https://sdgs.un.org/goals/goal7.

[31] UN, "Seventy-sixth session item 20(h) of the provisional agenda: education for sustainable development in the framework of the 2030 agenda for sustainable development note by the Secretary-General - A/RES/76/209.", 2022. Accessed: Feb. 25, 2024. [Online]. Available: https://digitallibrary.un.org/nanna/record/3954261/files/A_RES_76_209-EN.pdf.

[32] UNDP, "The SDGs in action - What are the sustainable development goals? | United Nations development programme", 2024. Accessed: Jan. 13, 2025. [Online]. Available: https://www.undp.org/sustainable-development-goals.

[33] C. Rapanta, L. Botturi, P. Goodyear, L. Guàrdia, M. Koole, Online university teaching during and after the Covid-19 crisis: refocusing teacher presence and learning activity, Postdigit. Sci. Educ. 2 (3) (2020) 923–945, https://doi.org/10.1007/s42438-020-00155-y.

[34] Y. Hao, et al., The origins of COVID-19 pandemic: a brief overview, Transbound. Emerg. Dis. 69 (6) (2022) 3181–3197, https://doi.org/10.1111/tbed.14732.

[35] D. Cucinotta, M. Vanelli, WHO declares COVID-19 a pandemic, Acta Biomed. 91 (1) (2020) 157–160, https://doi.org/10.23750/abm.v91i1.9397.

[36] A. Moubayed, M. Injadat, A.B. Nassif, H. Lutfiyya, A. Shami, E-Learning: challenges and research opportunities using machine learning data analytics, IEEE Access 6 (2018) 39117–39138, https://doi.org/10.1109/ACCESS.2018.2851790.

[37] D.A. Dutta, Impact of digital social media on Indian higher education: alternative approaches of online learning during COVID-19 pandemic crisis, Int. J. Sci. Res. Publ. IJSRP 10 (05) (2020) 604–611, https://doi.org/10.29322/IJSRP.10.05.2020.P10169.

[38] S. Malhotra, R. Dutta, A. Kumar, D.S. Mahna, Paradigm shift in engineering education during COVID 19: from chalkboards to talk boards, in: Proceedings of the 2020 12th International Conference on Computational Intelligence and Communication Networks, CICN 2020, 2020, pp. 287–293, https://doi.org/10.1109/CICN49253.2020.9242617.

[39] J. König, D.J. Jäger-Biela, N. Glutsch, Adapting to online teaching during COVID-19 school closure: teacher education and teacher competence effects among early career teachers in Germany, Eur. J. Teach. Educ. 43 (4) (2020) 608–622, https://doi.org/10.1080/02619768.2020.1809650.

[40] UNESCO, "Global education coalition", 2021. Accessed: Aug. 17, 2021. [Online]. Available: https://en.unesco.org/covid19/educationresponse/globalcoalition.

[41] T.J. Dunn, M. Kennedy, Technology enhanced learning in higher education; motivations, engagement and academic achievement, Comput. Educ. 137 (2019) 104–113, https://doi.org/10.1016/j.compedu.2019.04.004.

[42] J. Wang, D.E.H. Tigelaar, W. Admiraal, Rural teachers' sharing of digital educational resources: from motivation to behavior, Comput. Educ. 161 (2021) 104055, https://doi.org/10.1016/J.COMPEDU.2020.104055.

[43] C.D. Resendiz-Calderón, L.I. Farfan-Cabrera, I.O. Cazares-Ramírez, P. Nájera-García, K. Okoye, Assessing benefits of computer-based video training and tools on learning outcomes and motivation in mechanical engineering education: digitalized intervention and approach, Front. Educ. 9 (1292405) (2024), https://doi.org/10.3389/feduc.2024.1292405 (Lausanne).

[44] T.P. Falcão, R.F. Mello, R.L. Rodrigues, J.R.B. Diniz, Y.S. Tsai, D. Gašević, Perceptions and expectations about learning analytics from a brazilian higher education institution, ACM Int. Conf. Proc. Ser. (2020) 240–249, https://doi.org/10.1145/3375462.3375478.

[45] K. Okoye, S.D.N. Daruich, R. Castaño, J.F. Enríquez de la O, J. Escamilla, S. Hosseini, Analyzing the impact of digitized-education toward the future of education: a comparative study based on students' evaluation of teaching data, Stud. Educ. Eval. 82 (2024) 101359, https://doi.org/10.1016/j.stueduc.2024.101359.

[46] Z. Xu, H. Yuan, Q. Liu, Student performance prediction based on blended learning, IEEE Trans. Educ. 64 (1) (2021) 66–73, https://doi.org/10.1109/TE.2020.3008751.

[47] C.B. Mpungose, Student teachers' knowledge in the era of the fourth industrial revolution, Educ. Inf. Technol. 25 (6) (2020) 5149–5165, https://doi.org/10.1007/s10639-020-10212-5 (Dordr).

[48] UNESCO, "National learning platforms and tools", 2021. Accessed: Aug. 17, 2021. [Online]. Available: https://en.unesco.org/covid19/educationresponse/nationalresponses.

[49] S. Dhawan, Online learning: a panacea in the time of COVID-19 crisis, J. Educ. Technol. Syst. 49 (1) (2020) 5–22, https://doi.org/10.1177/0047239520934018.

[50] UNESCO, "Education and technological transformations for Human-centered recovery: the Global Education Coalition in action - ED/GEC/2021/04", 2021. Accessed: Oct. 27, 2021. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000379133.
[51] ICFE, "Reimagining our futures together: a new social contract for education - UNESCO report by International Commission on the Futures of Education (ICFE)," pp. 188, 2021. Accessed: Jun. 26, 2022. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000379707.
[52] N. Selwyn, "(Re)imagining the futures of lifelong learning: some sociotechnical tensions | UNESCO Institute for Lifelong Learning (UIL).", 2021. Accessed: Mar. 16, 2022. [Online]. Available: https://uil.unesco.org/lifelong-learning/reimagining-futures-lifelong-learning-some-sociotechnical-tensions.
[53] OECD, "Regulatory quality and COVID-19: managing the risks and supporting the recovery (Note by the Secretariat in Consultation With the Chairs and the Bureaus of the Regulatory Policy Committee and the Network of Economic Regulators) | Organisation for Economic Co-operation and Development", 2020. Accessed: May 10, 2021. [Online]. Available: https://www.oecd.org/coronavirus/policy-responses/regulatory-quality-and-covid-19-managing-the-risks-andsupporting-the-recovery-3f752e60/.
[54] OECD, "Back to the future of education: four OECD scenarios for schooling | OECD iLibrary,", 2020. In series: Educational Research and Innovation. Accessed: Mar. 09, 2022. [Online]. Available: https://www.oecd.org/education/back-to-the-future-s-of-education-178ef527-en.htm.
[55] UNESCO, "UNESCO's global education coalition gathers to discuss its future direction | Acting For Recovery, Resilience and Reimagining Education", 2021. Accessed: Nov. 18, 2021. [Online]. Available: https://en.unesco.org/news/unescos-global-education-coalition-gathers-discuss-its-future-direction.
[56] UNESCO, "UNESCO strategy on technological innovation in education (2022–2025) - UNESCO Digital Library", 2021. Accessed: May 22, 2022. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000378847.
[57] OECD, "How will COVID-19 reshape science, technology and innovation? - OECD", 2021. Accessed: Sep. 01, 2021. [Online]. Available: https://www.oecd.org/coronavirus/policy-responses/how-will-covid-19-reshape-science-technology-and-innovation-2332334d/.
[58] N. Carrete-Marín, L. Domingo-Peñafiel, Digital transformation and open education in rural schools (Transformación digital y educación abierta en la escuela rural), Prism. Soc. 41 (2023) 95–114.
[59] A.G. Rincón, S. Barragán, F.C. Vitery, Rurality and dropout in virtual higher education programmes in Colombia, Sustainability 13 (9) (2021) 4953, https://doi.org/10.3390/SU13094953, 2021, Vol. 13, Page 4953.
[60] J. Wang, D.E.H. Tigelaar, W. Admiraal, Connecting rural schools to quality education: rural teachers' use of digital educational resources, Comput. Hum. Behav. 101 (2019) 68–76, https://doi.org/10.1016/J.CHB.2019.07.009.
[61] Z. Hong, Strategies for enhancing the resilience of rural teachers from the perspective of Chinese rural school principals, in the post-pandemic period, Environ. Soc. Psychol. 8 (3) (2023), https://doi.org/10.54517/esp.v8i3.1963.
[62] D.J. Young, Rural and urban differences in student achievement in science and mathematics: a multilevel Analysis, School Effectiveness and School Improvement 9 (4) (2006) 386–418, https://doi.org/10.1080/0924345980090403.
[63] S. Gao, M. Yang, X. Wang, W. Min, S. Rozelle, Peer relations and dropout behavior: evidence from junior high school students in northwest rural China, Int. J. Educ. Dev. 65 (2019) 134–143, https://doi.org/10.1016/J.IJEDUDEV.2018.04.001.
[64] E.H.T. Oliveira, et al., Higher education in the Amazon: challenges and initiatives, Commun. Comput. Inf. Sci. 832 (2018) 17–31, https://doi.org/10.1007/978-3-319-97934-2_2/COVER.
[65] M.S. Khalid, M.J.L. Pedersen, Digital exclusion in higher education contexts: a systematic literature review, Procedia Soc. Behav. Sci. 228 (2016) 614–621, https://doi.org/10.1016/J.SBSPRO.2016.07.094.
[66] M. Abu Talib, A.M. Bettayeb, R.I. Omer, Analytical study on the impact of technology in higher education during the age of COVID-19: systematic literature review, Educ. Inf. Technol. 26 (6) (2021) 6719–6746, https://doi.org/10.1007/S10639-021-10507-1/TABLES/7 (Dordr).
[67] OECD, "Lessons for education from COVID-19", 2020. Accessed: Mar. 28, 2022. [Online]. Available: https://www.oecd-ilibrary.org/education/lessons-for-education-from-covid-19_0a530888-en.
[68] A. Kaklauskas, A. Abraham, S. Guggari, K. Okoye, Lessons from COVID-19: impact on healthcare systems and technology, Academic Press - Elsevier, Berkeley, CA, USA,1-432, p. 2022, doi:10.1016/C2021-0-00397-7A.
[69] K.R. Devkota, Inequalities reinforced through online and distance education in the age of COVID-19: the case of higher education in Nepal, Int. Rev. Educ. 67 (1) (2021) 145–165, https://doi.org/10.1007/S11159-021-09886-X, 2021 67:1.
[70] K. Okoye, et al., Impact of digital technologies upon teaching and learning in higher education in Latin America: an outlook on the reach, barriers, and bottlenecks, Educ. Inf. Technol. 28 (2) (2023) 2291–2360, https://doi.org/10.1007/S10639-022-11214-1 (Dordr) 2022 28:2.
[71] S. Khan, G.J. Hwang, M.Azeem Abbas, A. Rehman, Mitigating the urban–rural educational gap in developing countries through mobile technology-supported learning, Br. J. Educ. Technol. 50 (2) (2019) 735–749, https://doi.org/10.1111/BJET.12692.
[72] D.S. Aditya, Embarking digital learning due to COVID-19: are teachers ready? J. Technol. Sci. Educ. 11 (1) (2021) 104–116, https://doi.org/10.3926/jotse.1109.
[73] S. Tiwari, S.K. Srivastava, S. Upadhyay, An analysis of students' readiness and facilitators' perception towards E-learning using machine learning algorithms, in: Proceedings of the 2021 2nd International Conference on Intelligent Engineering and Management, ICIEM 2021, 2021, pp. 504–509, https://doi.org/10.1109/ICIEM51511.2021.9445296.
[74] V. Mncube, B.H. Mutongoza, E. Olawale, Managing higher education institutions in the context of COVID-19 stringency: experiences of stakeholders at a rural South African university, Perspect. Educ. 39 (1) (2021) 390–409, https://doi.org/10.18820/2519593X/PIE.V39.I1.24.
[75] UNESCO, "UNESCO member states unite to increase investment in education", 2021. Accessed: Mar. 13, 2022. [Online]. Available: https://en.unesco.org/news/unesco-member-states-unite-increase-investment-education.
[76] WUN, "Open and inclusive education: WUN and UNESCO training & research networks - Worldwide Univerties Network (WUN)", 2021. Accessed: Jul. 06, 2022. [Online]. Available: https://wun.ac.uk/wun/research/view/open-and-inclusive-education-wun-and-unesco-training-research-networks/.
[77] UNESCO, "International community rallies behind technological transformations for quality, equitable and inclusive education | Global Education Coalition", 2021. Accessed: Nov. 26, 2021. [Online]. Available: https://en.unesco.org/news/international-community-rallies-behind-technological-transformations-quality-equitable-and.
[78] A. Adel, J. Dayan, Towards an intelligent blended system of learning activities model for New Zealand institutions: an investigative approach, Humanit. Soc. Sci. Commun. 8 (1) (2021) 1–14, https://doi.org/10.1057/s41599-020-00696-4, 2021 8:1.
[79] K. Facer and N. Selwyn, "Digital technology and the futures of education – towards 'non-stupid' optimism | UNESCO - ED-2020/FoE-BP/27," pp. 19, 2021. Accessed: Mar. 15, 2022. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000377071.
[80] B.L. Moorhouse, K.M. Wong, Blending asynchronous and synchronous digital technologies and instructional approaches to facilitate remote learning, J. Comput. Educ. 9 (1) (2022) 51–70, https://doi.org/10.1007/S40692-021-00195-8/FIGURES/3.
[81] J.F. Kalolo, Digital revolution and its impact on education systems in developing countries, Educ. Inf. Technol. 24 (1) (2018) 345–358, https://doi.org/10.1007/S10639-018-9778-3 (Dordr) 2018 24:1.
[82] IEEE, "COVID-19 made internet access, broadband and hotspots an educational necessity | IEEE Transmitter", 2020. Accessed: Jun. 09, 2020. [Online]. Available: https://transmitter.ieee.org/covid-19-made-internet-access-broadband-and-hotspots-an-educational-necessity/.
[83] N. Landa, S. Zhou, N. Marongwe, Education in emergencies: lessons from COVID-19 in South Africa, Int. Rev. Educ. 67 (1–2) (2021) 167–183, https://doi.org/10.1007/S11159-021-09903-Z/TABLES/1.
[84] C. Müller, T. Mildenberger, Facilitating flexible learning by replacing classroom time with an online learning environment: a systematic review of blended learning in higher education, Educ. Res. Rev. 34 (2021) 100394, https://doi.org/10.1016/J.EDUREV.2021.100394.
[85] M.Z. Hoq, E-learning during the period of pandemic (COVID-19) in the Kingdom of Saudi Arabia: an empirical study, Am. J. Educ. Res. 8 (7) (2020) 457–464. Accessed: Aug. 15, 2022. [Online]. Available: http://www.sciepub.com/Education/abstract/12018.
[86] A. Elçi, A.M. Abubakar, The configurational effects of task-technology fit, technology-induced engagement and motivation on learning performance during Covid-19 pandemic: an fsQCA approach, Educ. Inf. Technol. 26 (6) (2021) 7259–7277, https://doi.org/10.1007/S10639-021-10580-6/TABLES/4 (Dordr).
[87] UNESCO, "Competency based education. Learning portal - planning education for improved learning outcome | Edu Trends Report", 2,4(2015), pp. 34, 2015. Accessed: Jun. 24, 2025. [Online]. Available: https://learningportal.iiep.unesco.org/en/library/competency-based-education.
[88] National Academies, "Equitable and resilient infrastructure investments", 2022. Accessed: Jul. 25, 2022. [Online]. Available: 10.17226/26633.
[89] S. Schneegans, J. Lewis, and T. Straza, "UNESCO science report: the race against time for smarter development - UNESCO Digital Library", pp. 736, 2021. Accessed: Apr. 04, 2022. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000377433.
[90] UNESCO, "The digital learning turn in Africa: the role of local ecosystems; Global Education Coalition celebrates Africa Day 2021", 2021. Accessed: Oct. 28, 2021. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000377725.
[91] UN, "Everyone included: social Impact of COVID-19 | DISD", 2021. Accessed: Aug. 30, 2021. [Online]. Available: https://www.un.org/development/desa/dspd/everyone-included-covid-19.html.
[92] J. Miranda, et al., The core components of education 4.0 in higher education: three case studies in engineering education, Comput. Electr. Eng., 93(2021), 107278, 2021. doi:10.1016/j.compeleceng.2021.107278.
[93] C.M. Chituc, A framework for education 4.0 in digital education ecosystems, IFIP. Adv. Inf. Commun. Technol. IFIPAICT 629 (2021) 702–709, https://doi.org/10.1007/978-3-030-85969-5_66.
[94] IEEE, "How COVID-19 is affecting industry 4.0 and innovation | IEEE Transmitter", 2020. Accessed: Jun. 05, 2020. [Online]. Available: https://transmitter.ieee.org/how-covid-19-is-affecting-industry-4-0-and-the-future-of-innovation/.
[95] P. Engzell, A. Frey, M.D. Verhagen, Learning loss due to school closures during the COVID-19 pandemic, Proc. Natl. Acad. Sci. U. S. A. 118 (17) (2021), https://doi.org/10.1073/pnas.2022376118.
[96] J. Groff, "Technology-rich innovative learning environments | OECD Working paper" 2013. Accessed: May 22, 2022. [Online]. Available: https://www.yumpu.com/en/document/view/42819533/technology-rich-innovative-learning-environments-by-jennifer-groff.

[97] P. Walsh, "Innovative technology is the future of education", 2020. Accessed: Mar. 21, 2022. [Online]. Available: https://www.forbes.com/councils/forbestechcouncil/2020/07/23/innovative-technology-is-the-future-of-education/.
[98] D. Istance, M. Kools, OECD work on technology and education: innovative learning environments as an integrating framework, Eur. J. Educ. 48 (1) (2013) 43–57, https://doi.org/10.1111/EJED.12017.
[99] A. Petersoni, H. Dumontii, M. Lafuente, and N. Lawiii, "Understanding innovative pedagogies: key themes to analyse new approaches to teaching and learning | OECD Working papers no. 172," 2018. Accessed: Jul. 06, 2021. [Online]. Available: https://www.oecd.org/en/publications/understanding-innovative-pedagogies_9f843a6e-en.html.
[100] L. Gorina, M. Gordova, I. Khristoforova, L. Sundeeva, W. Strielkowski, Sustainable education and digitalization through the prism of the COVID-19 pandemic, Sustainability 15 (8) (2023), https://doi.org/10.3390/su15086846 (Switzerland).
[101] F.A.Al. Husseiny, M.H. Abdallah, Higher education in the post-pandemic era: implications and future prospects," in Innovations in Digital Instruction Through Virtual Environ, IGI Global, USA 221–235 (2023) 2023, https://doi.org/10.4018/978-1-6684-7015-2.ch013.
[102] UIS, "Data for education - a guide for policymakers to leverage education data | UNESCO," 2023. Accessed: Feb. 07, 2024. [Online]. Available: https://ces.uis.unesco.org/wp-content/uploads/sites/23/2024/01/Data-for-Education-final.pdf.
[103] S. Mulla, L. Denks, and M. Kalantzis, " Rethinking Pedagogy: Exploring the Potential of Digital Technology in Achieving Quality Education", pp. 151, 2019. Accessed: Mar. 08, 2022. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000372786.
[104] I. Chatziprodromidou, T. Apostolou, and A. Vantarakis, "COVID-19 and environmental factors. a PRISMA-compliant systematic review," medRxiv, May 15, 2020. Accessed: Jun. 24, 2025. [Online]. Available doi:10.1101/2020.05.10.20069732.
[105] H.M. Endedijk, L.D. Breeman, C.J. van Lissa, M.M.H.G. Hendrickx, L. den Boer, T. Mainhard, The teacher's invisible hand: a meta-analysis of the relevance of teacher–student relationship quality for peer relationships and the contribution of student behavior, Review of Educational Research 92 (3) (2021) 370–412, https://doi.org/10.3102/00346543211051428.
[106] M.J. Page, et al., Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement, J. Clin. Epidemiol. 134 (2021) 103–112, https://doi.org/10.1016/J.JCLINEPI.2021.02.003.
[107] A.L. Sønderlund, E. Hughes, J. Smith, The efficacy of learning analytics interventions in higher education: a systematic review, Br. J. Educ. Technol. 50 (5) (2019) 2594–2618, https://doi.org/10.1111/bjet.12720.
[108] P.A. Alexander, Methodological guidance paper: the art and science of quality systematic reviews, Review of Educational Research 90 (1) (2020) 6–23, https://doi.org/10.3102/0034654319854352.
[109] M. Noetel, et al., Multimedia design for learning: an overview of reviews with meta-meta-analysis, Review of Educational Research 92 (3) (2022) 413–454, https://doi.org/10.3102/00346543211052329.
[110] T.D. Pigott, J.R. Polanin, Methodological guidance paper: high-quality meta-analysis in a systematic review, Review of Educational Research 90 (1) (2019) 24–46, https://doi.org/10.3102/0034654319877153.
[111] D.D. Prasetya, A. Pinandito, Y. Hayashi, T. Hirashima, Analysis of quality of knowledge structure and students' perceptions in extension concept mapping, Res. Pract. Technol. Enhanc. Learn. 17 (1) (2022) 1–25, https://doi.org/10.1186/S41039-022-00189-9, 2022 17:1.
[112] M. Leijon, P. Gudmundsson, P. Staaf, C. Christersson, Challenge based learning in higher education– a systematic literature review, Innov. Educ. Teach. Int. 59 (5) (2022) 609–618, https://doi.org/10.1080/14703297.2021.1892503.
[113] M.D.C. Cabral Gouveia, I. Menezes, T. Neves, Educational strategies to reduce the achievement gap: a systematic review, Front. Educ. 8 (2023), https://doi.org/10.3389/FEDUC.2023.1155741 (Lausanne).
[114] W.S. Yun, Digitalization challenges in education during COVID-19: a systematic review, Cogent Educ. 10 (1) (2023), https://doi.org/10.1080/2331186X.2023.2198981.
[115] S. Mekimah, R. Zighed, K. Mili, I. Bengana, Business intelligence in organizational decision-making: a bibliometric analysis of research trends and gaps (2014–2024), Discov. Sustain. 5 (1) (2024) 532, https://doi.org/10.1007/s43621-024-00692-7.
[116] IBM, "What is text mining?", 2024. Accessed: Jun. 27, 2024. [Online]. Available: https://www.ibm.com/topics/text-mining.
[117] K. Okoye, S.D.N. Daruich, J.F.E. De La O, R. Castano, J. Escamilla, S. Hosseini, A text mining and statistical approach for assessment of pedagogical impact of students' evaluation of teaching and learning outcome in education, IEEE Access 11 (2023) 9577–9596, https://doi.org/10.1109/ACCESS.2023.3239779.
[118] K. Okoye, A. Arrona-Palacios, C. Camacho-Zuñiga, J.A.G. Achem, J. Escamilla, S. Hosseini, Towards teaching analytics: a contextual model for analysis of students' evaluation of teaching through text mining and machine learning classification, Educ. Inf. Technol. 27 (3) (2022) 3891–3933, https://doi.org/10.1007/S10639-021-10751-5.
[119] R. Gao, H.E. Merzdorf, S. Anwar, M.C. Hipwell, A.R. Srinivasa, Automatic assessment of text-based responses in post-secondary education: a systematic review, Comput. Educ. Artif. Intell. 6 (2024) 100206, https://doi.org/10.1016/j.caeai.2024.100206.
[120] VOSviewer, "VOSviewer | visualizing scientific landscapes", 2024. Accessed: May 07, 2024. [Online]. Available: https://www.vosviewer.com/.
[121] Tableau, "Business intelligence and analytics software", 2024. Accessed: Jul. 14, 2024. [Online]. Available: https://www.tableau.com/.
[122] Rstudio, "RStudio - RStudio", 2023. Accessed: Apr. 19, 2023. [Online]. Available: https://rstudio.com/products/rstudio/.
[123] J. du Toit, A.H. Verhoef, Embodied digital technology and transformation in higher education, Transform. High. Educ. 3 (0) (2018) 8, https://doi.org/10.4102/THE.V3I0.52.
[124] M. Munro, The complicity of digital technologies in the marketisation of UK higher education: exploring the implications of a critical discourse analysis of thirteen national digital teaching and learning strategies, Int. J. Educ. Technol. High. Educ. 15 (11) (2018) Springer, https://doi.org/10.1186/s41239-018-0093-2.
[125] M. Rieckmann, "Learning to transform the world: key competencies in education for sustainable development | UNESCO Digital Library," In Issues and Trends in Education For Sustainable Development, p. 39–59, 2018. Accessed: Nov. 06, 2022. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000261802.
[126] S. Pokhrel, R. Chhetri, A literature review on impact of COVID-19 pandemic on teaching and learning, High. Educ. Future 8 (1) (2021) 133–141, https://doi.org/10.1177/2347631120983481.
[127] UNESCO, "Assessment for improved learning outcomes | UNESCO", 2022. Accessed: Nov. 06, 2022. [Online]. Available: https://www.unesco.org/en/education/assessment.
[128] IITE, "New publication of UNESCO IITE and SOU: the Analytical report on the use of advanced ICT for digital transformation of education | UNESCO IITE", 2022. Accessed: Aug. 17, 2022. [Online]. Available: https://iite.unesco.org/news/unesco-iite-and-sou-analytical-report-on-the-use-of-advanced-ict-for-digital-transformation-of-education/.
[129] Global Education Coalition, "Transforming education through innovation: the global education coalition leading in action | UNESCO Digital Library - ED/GEC/2022/01", 2022. Accessed: Apr. 05, 2022. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000381023.
[130] OECD, "The assessment of higher education learning outcomes - OECD", 2022. Accessed: Nov. 06, 2022. [Online]. Available: https://www.oecd.org/education/imhe/theassessmentofhighereducationlearningoutcomes.htm.
[131] World Bank, "Education overview: development news, research, data | World Bank", 2022. Accessed: Jul. 12, 2022. [Online]. Available: https://www.worldbank.org/en/topic/education/overview#2.
[132] H.A. Patrinos and E.V. Bustillo, "Lessons for the education sector from the COVID-19 pandemic | World Bank", 2022. Accessed: Mar. 28, 2022. [Online]. Available: https://blogs.worldbank.org/education/lessons-education-sector-covid-19-pandemic.
[133] UNESCO, "Artificial intelligence and the futures of learning | UNESCO", 2023. Accessed: Jan. 23, 2023. [Online]. Available: https://www.unesco.org/en/digital-education/ai-future-learning.
[134] K.G. Peres, P. Reher, R.D. de Castro, A.R. Vieira, COVID-19-related challenges in dental education: experiences from Brazil, the USA, and Australia, Pesqui. Bras. Odontopediatria Clín. Integr. 20 (suppl 1),SciELO, (2020). doi:10.1590/pboci.2020.130.
[135] N. Wieland, L.K. VidVersity, C. Manager, Online learning before, during and after COVID-19: observations over 20 years, Int. J. Adv. Corp. Learn. iJAC 13 (2) (2020) 84–92, https://doi.org/10.3991/ijac.v13i2.16779.
[136] K. Miwa and A. Blom, "Accelerating the EdTech ecosystem in the Middle East and North Africa | World Bank", 2021. Accessed: Dec. 04, 2024. [Online]. Available: https://blogs.worldbank.org/en/arabvoices/accelerating-edtech-ecosystem-middle-east-and-north-africa.
[137] UNESCO, "Covid-19 education: from disruption to recovery. School closures caused by Coronavirus (Covid-19)", 2020. Accessed: Sep. 09, 2020. [Online]. Available: https://en.unesco.org/covid19/educationresponse.
[138] UNESCO, "Education in a post-COVID world: nine ideas for public action | UNESCO Digital Library - ED-2020/WS/16", 2020. Accessed: May 16, 2022. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000373717.
[139] A.J. Ramos-Morcillo, C. Leal-Costa, J.E. Moral-García, M. Ruzafa-Martínez, Experiences of nursing students during the abrupt change from face-to-face to e-learning education during the first month of confinement due to COVID-19 in Spain, Int. J. Environ. Res. Public Health 17 (15) (2020) 5519, https://doi.org/10.3390/IJERPH17155519.
[140] P.K. Jena, Impact of pandemic covid-19 on education in india, J. Curr. Res. 12 (7) (2020) 12582–12586, https://doi.org/10.24941/ijcr.39209.07.2020.
[141] K. Jafar, K. Ananthpur, L. Venkatachalam, Digital divide and access to online education: new evidence from Tamil Nadu, India, J. Soc. Econ. Dev. 25 (2) (2023) 313–333, https://doi.org/10.1007/s40847-023-00236-1.
[142] A. Mikheev, Y. Serkina, A. Vasyaev, Current trends in the digital transformation of higher education institutions in Russia, Educ. Inf. Technol. (2021) 1–15, https://doi.org/10.1007/s10639-021-10467-6 (Dordr).
[143] M.V. Yakovlev and E.R. Burangulov, "Features of the development of the export potential of the Russian higher education system in the digital economy", In: Popkova, E.G. (eds) Business 4.0 as a Subject of the Digital Economy. Advances in Science, Technology & Innovation. Springer, Cham, pp. 17–21, 2022. doi:10.1007/978-3-030-90324-4_3.
[144] I. Hasin, M.K.M Nasir, The effectiveness of the use of information and communication technology (ICT) in rural secondary schools in Malaysia, J. Educ. e-Learn. Res. 8 (1) (2021) 59–64, https://doi.org/10.20448/JOURNAL.509.2021.81.59.64.
[145] D.E. Fatumo, S. Ngwenya, Online learning platforms and their roles in influencing pass rate in rural communities of South Africa: massive open online courses (MOOCs), 2020 2nd International Multidisciplinary Information Technology and

Engineering Conference, IMITEC 2020, Kimberley, South Africa, pp. 1-8,2020, doi:10.1109/IMITEC50163.2020.9334135.
[146] K. Braybrooke, S. Janes, and C. Sato, "Care-full Design sprints, online? Addressing gaps in cultural access and inclusion during Covid-19 with vulnerable communities in London and Tokyo", C&T '21: Communities & Technologies, Seattle WA USA, June 20 - 25, 2021, pp. 25–37, 2021, 10.1145/3461564.3461583.
[147] G. Moss et al., "The interactive whiteboards, pedagogy and pupil performance evaluation: an evaluation of the schools whiteboard expansion (SWE) project: London challenge with statistical analysis research", 2007. Accessed: June. 24, 2025. [Online]. Available:https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=5a10995c81aac275c42a65a13c434afc0b3f91ab.
[148] A. Alnemrat, H. Aldamen, M. Al-Deaibes, R. Alsharefeen, E-learning in a Jordanian higher education institution, Front. Psychol. 14 (2023), https://doi.org/10.3389/fpsyg.2023.1136142.
[149] M.A. Audah, M. Capek, and A. Patil, "COVID-19 and digital learning preparedness in Jordan | UNESCO", 2020. Accessed: Dec. 03, 2024. [Online]. Available: https://blogs.worldbank.org/en/arabvoices/covid-19-and-digital-learning-preparedness-jordan.
[150] Saudi Arabia Government, "Saudi Arabia vision 2030", 2024. Accessed: Dec. 03, 2024. [Online]. Available: https://www.vision2030.gov.sa/en.
[151] L.A. Ewing, H.B. Cooper, Technology-enabled remote learning during Covid-19: perspectives of Australian teachers, students and parents, Technol. Pedagogy Educ. 30 (1) (2021) 41–57, https://doi.org/10.1080/1475939X.2020.1868562.
[152] A.I. Al Alawi, S.A. Al Bassam, Evaluation of telecommunications regulatory practice in the Kingdom of Bahrain: development and challenges, Int. J. Bus. Inf. Syst. 31 (2) (2019) 282, https://doi.org/10.1504/IJBIS.2019.100282.
[153] T.J. Lopez-Garcia, J.A. Alvarez-Cedillo, T.A. Sanchez, C.M. Vicario-Solorzano, Review of trends in the educational model of distance education in Mexico, towards an education 4.0, Comput. Rev. J. 3 (2019) 2019. ISSN: 2581-6640.
[154] I. Mhamdi, H. Barka, Digital transformation in Morocco by 2025: how ADD is catalysing this transformation? ACM Int. Conf. Proc. Ser. (2021) 231–233, https://doi.org/10.1145/3460620.3460762.
[155] A.I. Khan, H. Al-Shihi, Z.A. Al-khanjari, M. Sarrab, Mobile Learning (M-Learning) adoption in the Middle East: lessons learned from the educationally advanced countries, Telemat. Inform. 32 (4) (2015) 909–920, https://doi.org/10.1016/j.tele.2015.04.005.
[156] A. Kilani, M. Hawamdeh, A. Qteishat, The role of higher education in influencing the politics of the middle east a comparative examination of the russian and turkish higher education models, in: Proceedings of the EDULEARN19: 11th International Conference on Education and New Learning Technologies, Palma, Span, 2019, pp. 2967–2972.
[157] S. Vosloo and E. Helsper, "A global review of selected digital inclusion policies | UNICEF", 2023. Accessed: Dec. 25, 2024. [Online]. Available: https://www.unicef.org/innocenti/reports/global-review-selected-digital-inclusion-policies.
[158] J. Mintz, C. Connolly, E. O'Brien, L. Daniela, T.J.Ó. Ceallaigh, Inclusive digital education: contexts, practices and perspectives, Comput. Sch. 41 (2) (2024) 115–119, https://doi.org/10.1080/07380569.2024.2340873.
[159] Statista, "Total information technology (IT) spending in Europe, the Middle East and Africa (EMEA) from 2019 to 2023 (in billion U.S. dollars) | Technology & Telecommunications", 2024. Accessed: Apr. 24, 2024. [Online]. Available: https://www.statista.com/statistics/780908/europe-middle-east-africa-it-spending-segments/.
[160] GPE, "Global partnership for education", 2022. Accessed: Mar. 13, 2022. [Online]. Available: https://www.globalpartnership.org/.
[161] LALA, "Building capacity to use learning analytics to improve higher education in Latin America (LALA Project)", 2020. Accessed: Mar. 04, 2023. [Online]. Available: https://cinda.cl/buenas_practicas/lala-project-building-capacity-to-use-learning-analytics-to-improve-higher-education-in-latin-america/.
[162] UNICEF MENA, "Reimagining life skills and citizenship education in the middle east and North Africa", 2017. Accessed: Nov. 25, 2024. [Online]. Available: https://www.unicef.org/mena/reports/reimagining-life-skills-and-citizenship-education-middle-east-and-north-africa.
[163] W. Benjelloun, Bridging the digital divide in higher education: north african challenges and initiatives. Higher Education in the Arab World, Springer Nature Switzerland, Cham, 2023, pp. 169–189, https://doi.org/10.1007/978-3-031-33568-6_10.
[164] UNESCO, "Transforming education in Africa through innovation: the global education coalition leading in action | UNESCO Digital Library", 2022. Accessed: May 30, 2022. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000381683.
[165] World Bank, "Digital technologies in education", 2024. Accessed: Nov. 01, 2024. [Online]. Available: https://www.worldbank.org/en/topic/edutech#1.
[166] A. Haleem, M. Javaid, M.A. Qadri, R. Suman, Understanding the role of digital technologies in education: a review, Sustain. Oper. Comput. 3 (2022) 275–285, https://doi.org/10.1016/j.susoc.2022.05.004.
[167] E. Livingston, et al., Global student perspectives on digital inclusion in education during COVID-19, Glob. Stud. Child. 13 (4) (2023) 341–357, https://doi.org/10.1177/20436106221102617.
[168] UNESCO, "Turning on mobile learning in Africa and the Middle East: illustrative initiatives and policy implications", 2012. Accessed: Nov. 26, 2024. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000216359.
[169] UNESCO, "Mobile learning for teachers in Africa and the Middle East: exploring the potential of mobile technologies to support teachers and improve practice", 2012. Accessed: Nov. 26, 2024. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000216358.
[170] Global Goals, "Goal 4: quality education - the global goals", 2023. Accessed: Jan. 02, 2024. [Online]. Available: https://www.globalgoals.org/goals/4-quality-education/.
[171] Global Goals, "Goal 10: reduced inequalities - the global goals", 2023. Accessed: Jan. 02, 2024. [Online]. Available: https://www.globalgoals.org/goals/10-reduced-inequalities/.
[172] Y. Zeng, Y. Zheng, X. Li, H. Ma, An effective path for rural teachers to use digital education resources in Chinese underdeveloped areas: a study based on grounded theory, in: Proceedings of the 2023 5th International Conference on Computer Science and Technologies in Education, CSTE 2023, 2023, pp. 275–281, https://doi.org/10.1109/CSTE59648.2023.00055.
[173] K. Okoye, J.T. Nganji, K.K. Hiran, S. Hosseini, Editorial: impact and implications of AI methods and tools for the future of education, Front. Educ. 9 (2024), https://doi.org/10.3389/feduc.2024.1434052 (Lausanne).
[174] M. Cevikbas, G. Greefrath, H.-S. Siller, Advantages and challenges of using digital technologies in mathematical modelling education – a descriptive systematic literature review, Front. Educ. 8 (2023) 161, https://doi.org/10.3389/FEDUC.2023.1142556 (Lausanne).
[175] R.I. Herrada, R. Baños, A. Alcayde, Student response systems: a multidisciplinary analysis using visual analytics, Educ. Sci. 10 (12) (2020) 348, https://doi.org/10.3390/EDUCSCI10120348 (Basel) 2020, Vol. 10, Page 348.
[176] M.-S. Chiu, Exploring models for increasing the effects of school information and communication technology use on learning outcomes through outside-school use and socioeconomic status mediation: the ecological techno-process, Educ. Technol. Res. Dev. 68 (2020) 413–436, https://doi.org/10.1007/s11423-019-09707-x.
[177] J. Tondeur, R. Scherer, F. Siddiq, E. Baran, Enhancing pre-service teachers' technological pedagogical content knowledge (TPACK): a mixed-method study, Educ. Technol. Res. Dev. 68 (2020) 319–343, https://doi.org/10.1007/s11423-019-09692-1.
[178] S.M. Hosseini, S.A. Boushehri, K. Alimohammadzadeh, Challenges and solutions for implementing telemedicine in Iran from health policymakers' perspective, BMC Health Serv. Res. 24 (1) (2024) 50, https://doi.org/10.1186/s12913-023-10488-6.
[179] B. Nieblas, K. Okoye, B. Carrión, N. Mehta, S. Mehta, Impact and future of telemedicine amidst the COVID-19 pandemic: a systematic review of the state-of-the-art in Latin America, Cienc Saude Coletiva 27 (8) (2022) 3013–3030, https://doi.org/10.1590/1413-81232022278.12532021.
[180] World Bank, "Remote learning, distance education and online learning during the COVID19 pandemic: A Resource List by the World Bank's Edtech Team", 2020. Accessed: Nov. 29, 2021. [Online]. Available: https://hdl.handle.net/10986/33499.
[181] W. Ali, Online and remote learning in higher education institutes: a necessity in light of COVID-19 pandemic, High. Educ. Stud. 10 (3) (2020) p16, https://doi.org/10.5539/HES.V10N3P16.
[182] J.Y. Wong, et al., Evaluations of virtual and augmented reality technology-enhanced learning for higher education, Electronics 13 (8) (2024) 1549, https://doi.org/10.3390/electronics13081549 (Basel).
[183] Center for Learning in Practice, "MENA higher education pedagogy, technology and the refugee experience | sustainable learning pathways to teacher digital fluency", 2021. Accessed: Nov. 25, 2024. [Online]. Available: https://connectedlearning4refugees.org/wp-content/uploads/2024/01/MENA_Project_Report.pdf.
[184] D.N. Tahat, et al., Technology enhanced learning in undergraduate level education: a case study of students of mass communication, Sustainability 15 (21) (2023) 15280, https://doi.org/10.3390/su152115280.
[185] T.-M. Pan, K.-C. Fan, A sustainable approach: increasing students' information-technology competences and job-seeking capabilities through course redesign using FIT framework and active learning pedagogy, Sustainability 12 (10) (2020) 4094, https://doi.org/10.3390/su12104094.
[186] Z. Yu, W. Xu, L. Yu, Constructing an online sustainable educational model in COVID-19 pandemic environments, Sustainability 14 (6) (2022), https://doi.org/10.3390/su14063598 (Switzerland).
[187] D. Fraisl, et al., Mapping citizen science contributions to the UN sustainable development goals, Sustain. Sci. (2020), https://doi.org/10.1007/s11625-020-00833-7.
[188] H.J. Kim, H.Y. Jang, Sustainable technology integration in underserved area schools: the impact of perceived student change on teacher continuance intention, Sustainability 12 (12) (2020) 4802, https://doi.org/10.3390/SU12124802, 2020, Vol. 12, Page 4802.
[189] T. Tran, et al., How digital natives learn and thrive in the digital age: evidence from an emerging economy, Sustainability 12 (9) (2020) 3819, https://doi.org/10.3390/SU12093819, 2020, Vol. 12, Page 3819.
[190] ICEF, "Trends shaping higher education in the Middle East and North Africa | international consultants for education and fairs", 2024. Accessed: Nov. 25, 2024. [Online]. Available: https://monitor.icef.com/2013/01/trends-shaping-higher-education-in-the-middle-east-and-north-africa/.
[191] T. Milberg, "The future of learning: how AI is revolutionizing education 4.0 | World Economic Forum", 2024. Accessed: Dec. 27, 2024. [Online]. Available: https://www.weforum.org/stories/2024/04/future-learning-ai-revolutionizing-education-4-0/.
[192] D. Henriksen, P. Mishra, R. Stern, Creative learning for sustainability in a world of AI: action, mindset, values, Sustainability 16 (11) (2024) 4451, https://doi.org/10.3390/su16114451.

[193] H.S. AlSagri, S.S. Sohail, Evaluating the role of artificial intelligence in sustainable development goals with an emphasis on 'quality education, Discov. Sustain. 5 (1) (2024) 458, https://doi.org/10.1007/s43621-024-00682-9.
[194] K.S. Suryanarayana, V.S.P. Kandi, G. Pavani, A.S. Rao, S. Rout, T. Siva Rama Krishna, Artificial intelligence enhanced digital learning for the sustainability of education management system, J. High Technol. Manag. Res. 35 (2) (2024) 100495, https://doi.org/10.1016/j.hitech.2024.100495.
[195] T. Amano, C. Rios Rojas, Y. Boum II, M. Calvo, B.B. Misra, Ten tips for overcoming language barriers in science, Nat. Hum. Behav. 5 (9) (2021) 1119–1122, https://doi.org/10.1038/s41562-021-01137-1.
[196] A. Squires, T. Sadarangani, S. Jones, Strategies for overcoming language barriers in research, J. Adv. Nurs. 76 (2) (2020) 706–714, https://doi.org/10.1111/jan.14007.
[197] G.W. Muschert, M. Ragnedda, Digital divide in the Middle East and North Africa: introduction to the special issue, Convergence 30 (3) (2024) 1099–1104, https://doi.org/10.1177/13548565241260458. The International Journal of Research into New Media Technologies.
[198] Muhaimin, Asrial, A. Habibi, A. Mukminin, P. Hadisaputra, Science teachers' integration of digital resources in education: a survey in rural areas of one Indonesian province, Heliyon 6 (8) (2020) e04631, https://doi.org/10.1016/J.HELIYON.2020.E04631.
[199] T.D. Oyedotun, Sudden change of pedagogy in education driven by COVID-19: perspectives and evaluation from a developing country, Res. Glob. 2 (2020) 100029, https://doi.org/10.1016/j.resglo.2020.100029.
[200] E. Abad-Segura, M.D. González-Zamar, J.C. Infante-Moro, G.R. García, Sustainable management of digital transformation in higher education: global research trends, Sustainability 12 (5) (2020) 2107, https://doi.org/10.3390/SU12052107, 2020, Vol. 12, Page 2107.
[201] S.-E. Kandri, "How COVID-19 is driving a long-overdue revolution in education." Accessed: Dec. 03, 2024. [Online]. Available: https://www.weforum.org/stories/2020/04/coronavirus-education-global-covid19-online-digital-learning/.
[202] M.A. Almaiah, A. Al-Khasawneh, A. Althunibat, Exploring the critical challenges and factors influencing the E-learning system usage during COVID-19 pandemic, Educ. Inf. Technol. 25 (6) (2020) 5261–5280, https://doi.org/10.1007/s10639-020-10219-y (Dordr).
[203] A.M. Kashyap, S.V. Sailaja, K.V.R. Srinivas, S.S. Raju, Challenges in online teaching amidst COVID crisis: impact on engineering educators of different levels, J. Eng. Educ. Transform. 34 (0) (2021) 38–43. Accessed: Jul. 25, 2021[Online]. Available: http://www.journaleet.in/index.php/jeet/article/view/157103.
[204] P. Nedungadi, R. Menon, G. Gutjahr, R. Raman, Evaluating holistic education and digital learning model for advancing SDG4: a longitudinal mixed-effects modeling approach, Cogent Soc. Sci. 10 (1) (2024), https://doi.org/10.1080/23311886.2023.2299134.
[205] N. Wright, E. Miller, L. Dawes, C. Wrigley, Beyond 'chalk and talk': educator perspectives on design immersion programs for rural and regional schools, Int. J. Technol. Des. Educ. 30 (1) (2020) 35–65, https://doi.org/10.1007/S10798-018-9487-7/TABLES/5.
[206] F.H. Rogers and S. Shwetlena, "The COVID-19 pandemic: shocks to education and policy responses", 2020. Accessed: Sep. 09, 2020. [Online]. Available: http://documents1.worldbank.org/curated/en/365801588601466966/pdf/The-COVID-19-Pandemic-Shocks-to-Education-and-Policy-Responses.pdf.
[207] R.C. Chick, et al., Using technology to maintain the education of residents during the COVID-19 pandemic, J. Surg. Educ. 77 (4) (2020) 729–732, https://doi.org/10.1016/j.jsurg.2020.03.018.
[208] L. Mishra, T. Gupta, A. Shree, Online teaching-learning in higher education during lockdown period of COVID-19 pandemic, Int. J. Educ. Res. Open 1 (2020) 100012, https://doi.org/10.1016/J.IJEDRO.2020.100012.
[209] OECD, Innovating Education and Educating for Innovation: the Power of Digital Technologies and Skills, Paris: OECD Publishing, 2022. Accessed: Jul. 28, [Online]. Available: https://www.oecd-ilibrary.org/education/innovating-education-and-educating-for-innovation_9789264265097-en.
[210] N. Butcher, "Technological infrastructure and use of ICT in education in Africa: an overview." 2003. Accessed: Nov. 20, 2024. [Online]. Available: https://www.adeanet.org/clearinghouse/sites/default/files/docs/dol_ICT_eng.pdf.
[211] World bank, "Digital skills for everyone", 2024. Accessed: Apr. 07, 2024. [Online]. Available: https://thedocs.worldbank.org/en/doc/f2ef1c5cb80d5eba6c39364247bef17c-0360022021/original/Digital-Skills-Overview-Comm-Brochure.pdf.
[212] S. Bashir and K. Miyamoto, "Digital skills : frameworks and programs | digital economy for Africa (DE4A) initiative | World Bank", 2020. Accessed: Apr. 07, 2024. [Online]. Available: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/562351611824219616/digital-skills-frameworks-and-programs.
[213] World Economic Forum, "Strategic intelligence - global issue: education, skills and learning", 2022. Accessed: May 23, 2022. [Online]. Available: https://intelligence.weforum.org/topics/a1Gb0000000LPFfEAO.
[214] UNESCO, "Global education monitoring report 2020: inclusion and education: all means all. Paris", 2020. Accessed: Mar. 08, 2023. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000373718.
[215] UNESCO, "Global Citizenship education: Preparing Learners For the Challenges of the 21st Century | UNESCO Digital Library", 2014. Accessed: Aug. 23, 2020. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000227729.
[216] Y. Niel, "Two years on, global education coalition partners reflect on innovations and opportunities for scale up | UNESCO", 2022. Accessed: Apr. 25, 2022. [Online]. Available: https://www.unesco.org/en/articles/two-years-global-education-coalition-partners-reflect-innovations-and-opportunities-scale.
[217] T. Kumakawa, A text mining examination of university students' learning program posters, Open Access Libr. J. 4 (2017) e3639, https://doi.org/10.4236/oalib.1103639.
[218] D.J. Litman, K. Forbes-Riley, Predicting student emotions in computer-human tutoring dialogues, Association for Computational Linguistics (ACL) (2004) 351–es, https://doi.org/10.3115/1218955.1219000.
[219] K. Okoye, et al., Impact of students evaluation of teaching: a text analysis of the teachers qualities by gender, Int. J. Educ. Technol. High. Educ. 17 (1) (2020) 49, https://doi.org/10.1186/s41239-020-00224-z.
[220] A.H.K. Mohammed, H.-H. Jebamikyous, D. Nawara, R. Kashef, IoT text analytics in smart education and beyond, J. Comput. High. Educ. 2021 (2021) 1–28, https://doi.org/10.1007/S12528-021-09295-X.
[221] C. Tseng, J. Chou, Y. Tsai, Text mining analysis of teaching evaluation questionnaires for the selection of outstanding teaching faculty members, IEEE Access 6 (2018) 72870–72879, https://doi.org/10.1109/ACCESS.2018.2878478.
[222] E. Crossfield, M.F. Damian, The role of valence in word processing: evidence from lexical decision and emotional Stroop tasks, Acta Psychol. 218 (2021) 103359, https://doi.org/10.1016/j.actpsy.2021.103359 (Amst).
[223] L. Tian, C. Lai, and J.D. Moore, "Polarity and intensity: the two aspects of sentiment analysis", 2018.Accessed: Mar. 10, 2022. [Online]. Available: https://arxiv.org/abs/1807.01466.
[224] Y. Niu, X. Zhu, J. Li, G. Hirst, Analysis of polarity information in medical text, in: Proceedings of the AMIA Annual Symposium 2005, 2005, pp. 570–574. AMIA Symposium. AMIA SymposiumAccessed: Mar. 21, 2021[Online]. Available: /pmc/articles/PMC1560818/.
[225] V. Shuman, D. Sander, K.R. Scherer, Levels of valence, Front. Psychol. 4 (2013), https://doi.org/10.3389/fpsyg.2013.00261.
[226] F. Tian, Q. Zheng, D. Zheng, Mining patterns of e-Learner emotion communication in turn level of Chinese interactive texts: experiments and findings, in: Proceedings of the 2010 14th International Conference on Computer Supported Cooperative Work in Design, CSCWD 2010, 2010, pp. 664–670, https://doi.org/10.1109/CSCWD.2010.5471892.
[227] K. Okoye, et al., Impact of digital technologies upon teaching and learning in higher education in Latin America: an outlook on the reach, barriers, and bottlenecks, Educ. Inf. Technol. 2022 (2022) 1–70, https://doi.org/10.1007/S10639-022-11214-1.
[228] F. Reimers, A. Schleicher, J. Saavedra, and S. Tuominen, "Supporting the continuation of teaching and learning during the COVID-19 Pandemic | Annotated Resources For Online Learning", 2020. Accessed: Aug. 23, 2020. [Online]. Available: https://www.oecd.org/education/Supporting-the-continuation-of-teaching-and-learning-during-the-COVID-19-pandemic.pdf.
[229] A. Aristovnik, D. Keržič, D. Ravšelj, N. Tomaževič, L. Umek, Impacts of the COVID-19 pandemic on life of higher education students: a global perspective, Sustainability 12 (20) (2020) 8438, https://doi.org/10.3390/SU12208438, 2020, Vol. 12, Page 8438.
[230] H.T.T. Dao, T.T.K. Le, Transitioning from traditional learning to blended learning at some public universities in Vietnam after the Covid-19 pandemic, ACM Int. Conf. Proc. Ser. (2020) 85–91, https://doi.org/10.1145/3441417.3441429.
[231] A. Kundu, T. Bej, COVID-19 response: students' readiness for shifting classes online, Corp. Gov. 21 (6) (2020) 1250–1270, https://doi.org/10.1108/CG-09-2020-0377/FULL/XML (Bingley).
[232] A. Jimoyiannis, N. Koukis, P. Tsiotakis, Shifting to emergency remote teaching due to the COVID-19 pandemic: an investigation of Greek teachers' beliefs and experiences, Commun. Comput. Inf. Sci. CCIS 1384 (2020) 320–329, https://doi.org/10.1007/978-3-030-73988-1_25.
[233] J. Lennox, N. Reuge, F. Benavides, UNICEF's lessons learned from the education response to the COVID-19 crisis and reflections on the implications for education policy, Int. J. Educ. Dev. 85 (2021) 102429, https://doi.org/10.1016/J.IJEDUDEV.2021.102429.
[234] M. B. Gerrard, "Public-private partnerships | Finance and Development Magazine | IMF", 38(3), 2001. Accessed: Apr. 14, 2024. [Online]. Available: https://www.imf.org/external/pubs/ft/fandd/2001/09/gerrard.htm.
[235] M. Fung, R. Taal, W. Sim, S. Ra, Jagannathan, S. S . , R. Maclean, SkillsFuture: the roles of public and private sectors in developing a learning society in Singapore, (eds) Powering a Learning Society During an Age of Disruption. Education in the Asia-Pacific Region: Issues, Concerns and Prospects, 58 (2021) 195–208, https://doi.org/10.1007/978-981-16-0983-1_14. Springer, Singapore.
[236] K. Gillespie, D.L. Robertson, and Associates, "A guide to faculty development – POD network: professional and organizational development network in higher education", 2010. Accessed: Dec. 03, 2022. [Online]. Available: https://podnetwork.org/publications/guide-to-faculty-development/.
[237] F. Boninger, A. Molnar, and C. Saldaña, "Personalized learning and the digital privatization of curriculum and teaching", 2019. Accessed: Sep. 21, 2021. [Online]. Available: https://nepc.colorado.edu/publication/personalized-learning.
[238] Learning Equality, "Bridging the digital divide to foster effective learning | learning equality", 2022. Accessed: May 15, 2022. [Online]. Available: https://learningequality.org/.
[239] Global Goals, "Goal 11: sustainable cities and communities - the global goals", 2023. Accessed: Jan. 01, 2025. [Online]. Available: https://www.globalgoals.org/goals/11-sustainable-cities-and-communities/.
[240] UN, "Education for all | United Nations", 2022. Accessed: Mar. 26, 2022. [Online]. Available: https://www.un.org/en/academic-impact/education-all.
[241] A. Boring, Gender biases in student evaluations of teaching, J. Public Econ. 145 (2017) 27–41, https://doi.org/10.1016/j.jpubeco.2016.11.006.

[242] UNICEF, "Girls' education - gender equality in education benefits every child | UNICEF - for every Child - UNICEF/UN0284179/LeMoyne", 2021. Accessed: Nov. 11, 2021. [Online]. Available: https://www.unicef.org/education/girls-education.
[243] UNESCO, "United Nations alert that education should be a clear priority", 2021. Accessed: Mar. 10, 2022. [Online]. Available: https://en.unesco.org/news/united-nations-alert-education-should-be-clear-priority.
[244] UNESCO, "Education research and foresight", 2021. Accessed: May 02, 2022. [Online]. Available: https://en.unesco.org/themes/education/research-foresight.
[245] UNESCO, "UNESCO 2021 world conference on education for sustainable development", 2021. Accessed: Mar. 10, 2022. [Online]. Available: https://en.unesco.org/events/ESDfor2030.
[246] I. Seetal, S. Gunness, V. Teeroovengadum, Educational disruptions during the COVID-19 crisis in small island developing states: preparedness and efficacy of academics for online teaching, Int. Rev. Educ. 67 (1) (2021) 185–217, https://doi.org/10.1007/S11159-021-09902-0, 2021 67:1.
[247] IEA, "Response to educational disruption survey | REDS", 2022. Accessed: May 15, 2022. [Online]. Available: https://www.iea.nl/studies/iea/REDS.
[248] UNESCO, "Official list of SDG 4 indicators FFA education 2030 framework for action", 2022. Accessed: Jul. 06, 2022. [Online]. Available: https://tcg.uis.unesco.org/wp-content/uploads/sites/4/2020/09/SDG4_indicator_list.pdf.
[249] J. Escamilla, "Power skills: preparing students for the Future of work - world innovation summit for education (WISE)", 2018. Accessed: Aug. 25, 2022. [Online]. Available: https://www.wise-qatar.org/power-skills-preparing-students-for-future-of-work-jose-escamilla/.
[250] CONECTA, "Tec de Monterrey and UNAM join forces: create research consortium", 2021. Accessed: Aug. 18, 2021. [Online]. Available: https://tec.mx/es/noticias/nacional/institucion/se-unen-el-tec-de-monterrey-y-unam-crean-consorcio-de-investigacion.
[251] B.K. Engen, Understanding social and cultural aspects of teachers' digital competencies. Compren-diendo los aspectos culturales y sociales de las competencias digitales docentes, Comunicar 61 (XXVII) (2019), https://doi.org/10.3916/C61-2019-01.
[252] A. Garcez, R. Silva, M. Franco, Digital transformation shaping structural pillars for academic entrepreneurship: a framework proposal and research agenda, Educ. Inf. Technol. (2021) 1–24, https://doi.org/10.1007/s10639-021-10638-5 (Dordr).
[253] V. Corvello, M. De Carolis, S. Verteramo, A. Steiber, The digital transformation of entrepreneurial work, Int. J. Entrep. Behav. Res. (2021), https://doi.org/10.1108/IJEBR-01-2021-0067.
[254] World Bank, "World development indicators | Rural population (% of total population) | Data", 2022. Accessed: Aug. 23, 2022. [Online]. Available: https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?most_recent_value_desc=true.
[255] J. Suoranta, M. Teräs, H. Teräs, Rise of a 'Managerial demiurge': critical analysis of the digitalization of education, in: A. Abdi, G. Misiaszek, J. Popoff (Eds.), Palgrave Handbook on Critical Theories of Education, Palgrave, London, 2022.
[256] M. Teräs, J. Suoranta, H. Teräs, M. Curcher, Post-Covid-19 education and education technology 'solutionism': a seller's market, Postdigit. Sci. Educ. 2 (3) (2020) 863–878, https://doi.org/10.1007/S42438-020-00164-X, 2020 2:3.
[257] J. Suoranta, et al., Speculative social science fiction of digitalization in higher education: from what is to what could be, Postdigit. Sci. Educ. 4 (2) (2022) 224–236, https://doi.org/10.1007/S42438-021-00260-6, 2021 4:2.
[258] H. Mahfoodh, H. Alatawi, Sustaining higher education through e-Learning in post COVID-19, in: Proceedings of the International Conference on e-Learning, ICEL 2020, 2020, pp. 361–365, https://doi.org/10.1109/ECONF51404.2020.9385477. -December.
[259] TeachForAll, "#DONTSTOPLEARNING | teach for all", 2022. Accessed: May 15, 2022. [Online]. Available: https://teachforall.org/dontstoplearning.
[260] V.A. Samane-Cutipa, A.M. Quispe-Quispe, F. Talavera-Mendoza, C. H. Limaymanta, Digital gaps influencing the online learning of rural students in secondary education: a systematic review, Int. J. Inf. Educ. Technol. 12 (7) (2022) 685–690, https://doi.org/10.18178/ijiet.2022.12.7.1671.
[261] W. Strielkowski, E.N. Korneeva, A.K. Neshcheret, L.A. Sundeeva, Sustainable education at higher education institutions (HEIs) and the COVID-19 pandemic: a bibliometric review study field review, Integr. Educ. 28 (1) (2024) 22–39, https://doi.org/10.15507/1991-9468.114.028.202401.022-039.
[262] L.M. Allanina, E.A. Smirnova, E.A. Kalafatov, I.G. Shadskaja, S.A. Shirokovskikh, Sustainable development of rural areas: increasing employment in the context of digital technologies development, J. Adv. Res. Dyn. Control Syst. 12 (4) (2020) 1069–1076, https://doi.org/10.5373/JARDCS/V12SP4/20201580.
[263] B. Yu, W.Y. Guo, Y. Huang, Y. Hu, M. Jia, How did the COVID-19 pandemic exacerbate the digital divide at secondary education: the case of two Chinese schools, Educ. Stud. 59 (5–6) (2023) 504–521, https://doi.org/10.1080/00131946.2023.2274345. AESA.
[264] African Union, "Digital transformation strategy for Africa (2020-2030)", 2020. Accessed: Apr. 24, 2024. [Online]. Available: https://au.int/sites/default/files/documents/38507-doc-dts-english.pdf.
[265] S.J. Marshall, Shaping the university of the future | Using technology to catalyse change in university learning and teaching, Springer Nature Singapore Pte Ltd (2018) 1–592, https://doi.org/10.1007/978-981-10-7620-6. Singapore.
[266] K. Jones, "How technology is shaping the future of education", 2020. Accessed: Mar. 21, 2022. [Online]. Available: https://www.visualcapitalist.com/how-technology-is-shaping-the-future-of-education/.
[267] UNESCO, "UNESCO strategy on education for health and well-being: contributing to the sustainable development goals | UNESCO Digital Library", 2016. Accessed: Jun. 27, 2020. [Online]. Available: https://unesdoc.unesco.org/ark:/48223/pf0000246453.