Heliyon 9 (2023) e16348

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Systematic review and meta-analysis

Challenges, opportunities, and prospects of adopting and using smart digital technologies in learning environments: An iterative review ☆

Siyabonga Mhlongo [a,*], Khanyisile Mbatha [b], Boitumelo Ramatsetse [c], Reuben Dlamini [c,**]

[a] Department of Applied Information Systems, University of Johannesburg, Johannesburg, South Africa
[b] Department of Adult Continuing and Community Education, University of South Africa, Pretoria, South Africa
[c] Educational Information and Engineering Technology, University of the Witwatersrand, Johannesburg, South Africa

ARTICLE INFO

Keywords:
Digitalisation affordances
Digital pedagogy
Smart digital technologies
Brick-and-mortar education
Complexity theory
Iterative review

ABSTRACT

The adoption of smart digital technologies in the education system has grown exponentially over the years, creating new possibilities to improve teaching and enhance learning. Against this backdrop, the 'brick-and-mortar' education approach survives on life support, with digital technologies promoting ubiquitous teaching and learning. Through complexity theory, this study uses an iterative review research approach comprising of nine steps to frame the study of smart digital education. The complexity theory lens provides an appropriate framework to reason about the complexities that surface due to interactions of the elements of smart digital technologies in the education system. The complementary strength of the adopted methodological approach led to multiple discourses on technology-enabled and technology-enhanced learning environments. In particular, four broad themes emerged, which demonstrated the prevalence of various technologies and how they interact as a means of making sense of the emerging digitally-enabled education environment. Through these themes, this paper highlights digitalisation affordances (which include multimodality, a/synchronicity, and new forms of engagement), discusses the key challenges and complexities of digitally enabled education, and advances the discourse on how digitalisation can support and promote inclusivity amidst historic challenges. Finally, it discusses how the advancement of technologies provides a new paradigm of learning, revolutionises knowledge construction, and extends and enriches the 'brick-and-mortar' learning environment to enhance the educational experience. As a future research agenda, this paper recommends comprehensive end-to-end programmes and innovative ways to conceptualise and execute digitally-enabled education that provides equity-oriented opportunities for cognitive development.

☆ This article is a part of the "Smart digital technology use in the education sector" Special issue.

* Corresponding author.
** Principal corresponding author.
E-mail addresses: siyabongam@uj.ac.za (S. Mhlongo), reuben.dlamini@wits.ac.za (R. Dlamini).

https://doi.org/10.1016/j.heliyon.2023.e16348

Available online 18 May 2023

1. Introduction and background

The adoption of smart digital technologies in the education system has grown exponentially over the past few years. This has created new possibilities, predicaments, and challenges in contemporary society [1]. These technologies have been most prevalent in advanced private and public schools, but recently, they have reached the most disadvantaged schools around the globe. Many of these schools and teachers rely on smart digital technologies to assist learners in their education. The pervasiveness and the affordances of digital technologies are transforming the teaching and learning spaces. The boundaries of learning have been extended beyond the 'brick-and-mortar' through technology-supported instructional (TSI) activities. The complementary strength between technology-enhanced learning (TEL) and traditional approaches to teaching is becoming more visible. For example, technology-enabled smart boards are slowly replacing the traditional chalkboards and textbooks in classrooms. Central to this transition are educators, who remain the custodians of classroom pedagogical discourse. In TEL, digital competence and digital literacy are of critical importance.

To date, there has been a growing debate in literature as to whether future education, which encompasses the adoption of smart digital technologies, will replace the traditional 'brick-and-mortar' education system [2–4]. There is agreement in the literature that the future of education will be more personalised [2–4] and self-paced [5–8], which will aid learners to gradually progress from simple to more complicated concepts in the classroom. With this approach, learners are more likely to progress effortlessly in their learning, with less intervention by educators.

The integration of digital and internet technologies in education plays an important role in extending the boundaries of teaching and learning. However, to experience meaningful integration of digital and internet technologies, there is a need to understand their pedagogical affordances in education, and to further substantiate the arguments with practical cases. As a result of digitalisation in education, there have been innovative approaches to teaching and learning. To this effect, students must be prepared to use smart devices to improve their learning, comprehension, attentiveness, and literacy.

In this new normal, teachers play more of a facilitative and coordinating role, which means that more attention can be focused on guiding learners to solve problems in classrooms. This is an indication of collaborative and cooperative learning environments, which strive towards supporting highly interactive learning spaces. In accordance with social interdependence theory [9], cooperative learning is described as "the instructional use of small groups so that students work together to maximize their own and each other's learning" [10, p. 87]. Johnson and Johnson [9, p. 366] underpin effective cooperation on five essential mediating elements: "positive interdependence, individual accountability, promotive interaction, the appropriate use of social skills, and group processing". Collaborative learning is associated with the social constructivist approach to education, which encourages students to construct their own knowledge. A social constructivist approach is premised on the primacy of social interaction as the driving force to learning [11]. At the present time, various digital technologies have been developed, and the advent of the Fourth Industrial Revolution (4IR) provides opportunities for highly innovative teaching and learning practices. The pedagogical affordances of digital technologies, and the prospects of the 4IR, have the potential to transform the education landscape. This implies that schools, teachers, and government institutions will need to embrace the various prospects that will result in these changes.

In the current setting, this review paper seeks to explore and explicate the challenges, opportunities, and prospects of adopting and using smart digital technologies in learning environments. Indeed, taken in isolation, technology, teaching, and learning are all complex and dynamic constructs. Conjoining them creates a confluent super construct, which is both necessarily progressive and complex. For this reason, this paper adopts a theoretical and philosophical lens of complexity theory (through an iterative review approach), which is appropriate for exploring the reciprocal relationship between entities which are in constant flux. To guide and focus the review process, the following research questions were formulated:

RQ1: What are the contextual challenges that have necessitated the adoption of smart digital technologies in education to address societal issues?

RQ2: What are the potential opportunities that can be unlocked by integrating smart digital technologies with the discourse of teaching and learning?

RQ3: How can these opportunities be adopted to enhance students' understanding and improve academic achievement?

RQ4: How can smart digital technologies support an ecosystem of ubiquitous, quality, affordable and accessible education?

Although the prevalence of smart digital technologies in education is a global interest, this paper grounds its argument in the context of a developing country, South Africa. It is in this and similar emerging economies that the use of such technologies has the potential to fast-track socioeconomic development for the benefit of the citizenry.

The remainder of this paper is structured as follows: the next section outlines the methodological approach that guided the inquiry into the review presented in this paper; following that is a section that presents an argument on the demise of the 'brick-and-mortar' monopoly in education in the context of a developing country; this is followed by a reflective view of the prevalence of digital technologies in learning environments from the late nineteenth century to the present and beyond; this dovetails into the discussion of the utility of smart digital technologies in teaching and learning; the section that follows discusses the intersection of people, technology, and data to improve education, premised on the inevitability that large volumes of data are produced as a result of using technologies in teaching and learning practices. The paper concludes with a synthesised view of the foregoing, and highlights some implications.

2. Methodological approach

While they might aid in drastically simplifying the complex nature of teaching and learning in educational spaces, smart digital technologies and their associated approaches are anything but simple. Therefore, it is important to adopt a fitting theoretical and philosophical lens that will allow for apt inquiry when considering the challenges, opportunities, and prospects of using smart digital technologies in education systems. Mason [12, p. 9] argues that complexity theory allows for researchers to start thinking about “how we might usefully apply concepts and procedures derived from the study of other complex dynamical systems to analyzing systemic change in education”. Furthermore, through the complexity theory lens, we are able to explore the reality of emerging and existing “non-linear relationships between constantly changing entities” [13, p. 406], which is what results from the introduction and rapid uptake of technology in education.

This review study adopted an iterative literature review approach through the theoretical and philosophical lens of complexity theory to explore the challenges, opportunities, and prospects of using smart digital technologies and their associated approaches in education systems. This is depicted in Fig. 1. Unlike other literature review approaches, the iterative approach allows the researcher to progressively develop and refine the process of inquiry with each iteration, supported by a robust collection of relevant literature. Wisker [14] affirms that such an approach is key in “enabling learning, deepening of understanding and clarification through articulation” (p. 66). The research team comprised four academics with expertise in curriculum and instruction, instructional design, educational technology, engineering methods, information systems, computational science, and information and communication technology (ICT) from various top higher education institutions in South Africa. The overall expertise and experience of the research team strengthened the research approach to reveal different perspectives. Fig. 1 further illustrates the research process flow, incorporating focused brainstorming sessions for critiquing and consolidating inputs based on reviews of various research articles and reports from credible sources.

The process started by identifying the research problem and formulating research questions to establish boundaries on the use of smart digital technology in education. This was followed by developing an overarching research framework based on the identified thematic areas. Various topics were assigned to each member of the research team based on their respective expertise and experiences. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement updated in 2020 was adopted to guide and assist with the methodical approach in identifying, screening, and including or excluding literature based on the thematic areas identified [15,16]. The preference for the PRISMA approach was based on its exhaustive and transparent methodology. The overall process is illustrated in Fig. 2.

A preliminary and comprehensive literature study was conducted on using smart digital technologies in classrooms spanning the period: 1890s to 2020s (and into the future). This yielded a total of 5771 records. Of these, 5649 records were identified by using a comprehensive search strategy on the Core Collection of Clarivate’s Web of Science (WoS) platform, which is one of two credible platforms that provide consolidated access to multiple research databases (the other being Elsevier’s Scopus). The search strategy employed the following basic search string applied to all searchable fields of the WoS platform: (education AND (“digital technolog*” OR “smart technolog*” OR “digital pedagogy” OR “technolog* use” OR “technolog* integration”)). The use of quotation marks and wildcard symbols was adopted in order to include variations of the search terms. In addition to this search string, further limitations were applied to the search results to include records that met the following criteria:

(i) authored only in English;
(ii) of all types, excluding: Data Paper, Correction, Meeting Abstract, Book Review, Letter, and News Item; and
(iii) published by the top ten publishers (or research databases) when ranked by the number of records returned by the search string from each, which comprised: Taylor & Francis, Springer Nature, Elsevier, MDPI, Sage, Wiley, Emerald Group Publishing, Frontiers Media SA, JMIR Publications, Inc., and IEEE.

Without these limitations, the number of records would have been unmanageable for subsequent analysis and synthesis stages. Due to its reputation for indexing high-impact research works and its advanced searching and filtering options, which were crucial in the pre-screening process, the WoS platform was the preferred choice over the Scopus platform for the identification of relevant literature. In addition to the 5649 records identified through the WoS platform, the remaining 122 records were obtained through manual and citation sources, which included Google Scholar, the ACM Digital Library, and ResearchGate. The PRISMA approach allowed for these additional sources to be included, as the applied limitations may have excluded some potentially valuable records from the search results.

The screening process focused on identifying those records that would help illuminate the challenges, opportunities, and prospects of using smart digital technologies and their associated approaches in classroom settings. This effort was guided by the identified thematic areas. The research team members were accountable through regular brainstorming and consolidating sessions that were essential in the analysis of the preliminary findings. This was also characteristic of the iterative literature review process, and helped the team to deliver insightful findings. These regular sessions further assisted in consolidating and critiquing the research activity feedback in order to inform the next steps. After excluding 5619 records, primarily through human screening of titles and keywords ($n = 5440$) and abstracts ($n = 69$), and using automatic spreadsheet macros to eliminate duplicates and other erroneous records ($n = 110$), a total of 152 records remained for further analysis, the reports of which were all successfully retrieved. These reports were all assessed for eligibility by thoroughly examining their content. Specifically, eligibility was assessed by evaluating the extent to which the report discussed the adoption and application of smart digital technologies in educational settings, the inclusion and robustness of empirical findings, conceptual or theoretical justifications, the appropriate use of frameworks, as well as the relevancy

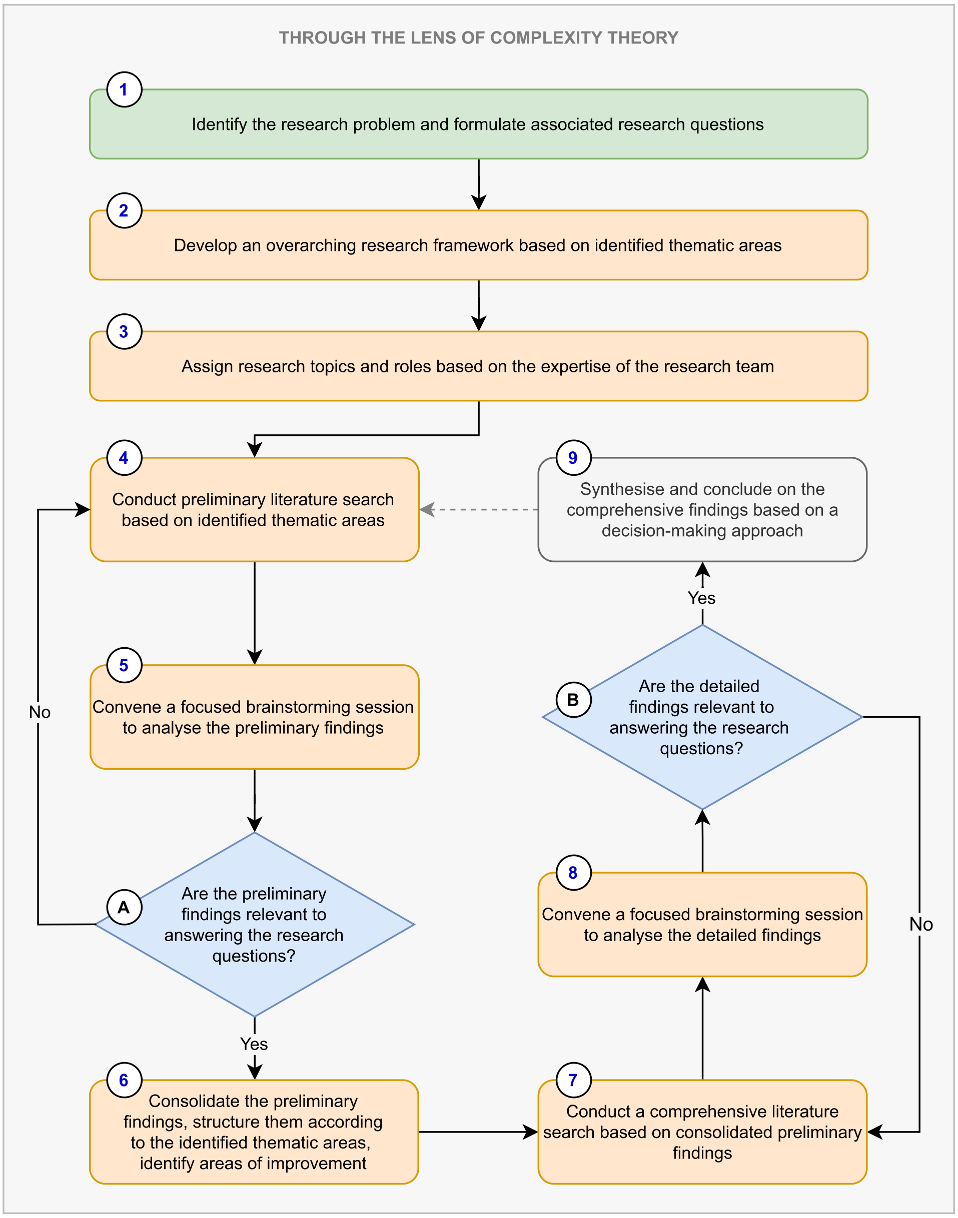

Fig. 1. Iterative research approach through the theoretical and philosophical lens of complexity theory (Source: the authors).

of case studies. Through this process, a further 8 reports were excluded as they did not fulfil these criteria, and thus did not align with the thematic areas.

In the end, the screening process resulted in a total of 144 reports for final review and analysis. These were subsequently classified into 8 focus areas (as depicted in Fig. 3) and 8 major article types (as depicted in Fig. 4).

There were four broad themes that emerged as a result of this iterative review approach, which are: (i) the role technology continues to play in eroding the monopoly of the traditional approach to teaching and learning, which confines the teaching and learning process to a physical space and a specific time; (ii) the transformative power of technology in learning spaces evidenced since the late nineteenth century to the present; (iii) the key digital technologies that have shaped the current educational landscape, and those that will continue to drive it into the future; and (iv) the three-way intersection of people, technology, and data as smart digital technologies become increasingly embedded within learning spaces. These are discussed in the following sections, starting with the former.

3. The demise of the brick-and-mortar monopoly

Public education is South Africa's great conundrum, and the restructuring of the curriculum in an effort by the government to achieve equal opportunities for all has not yielded any results. Therefore, for South Africa to meet its constitutional obligation to

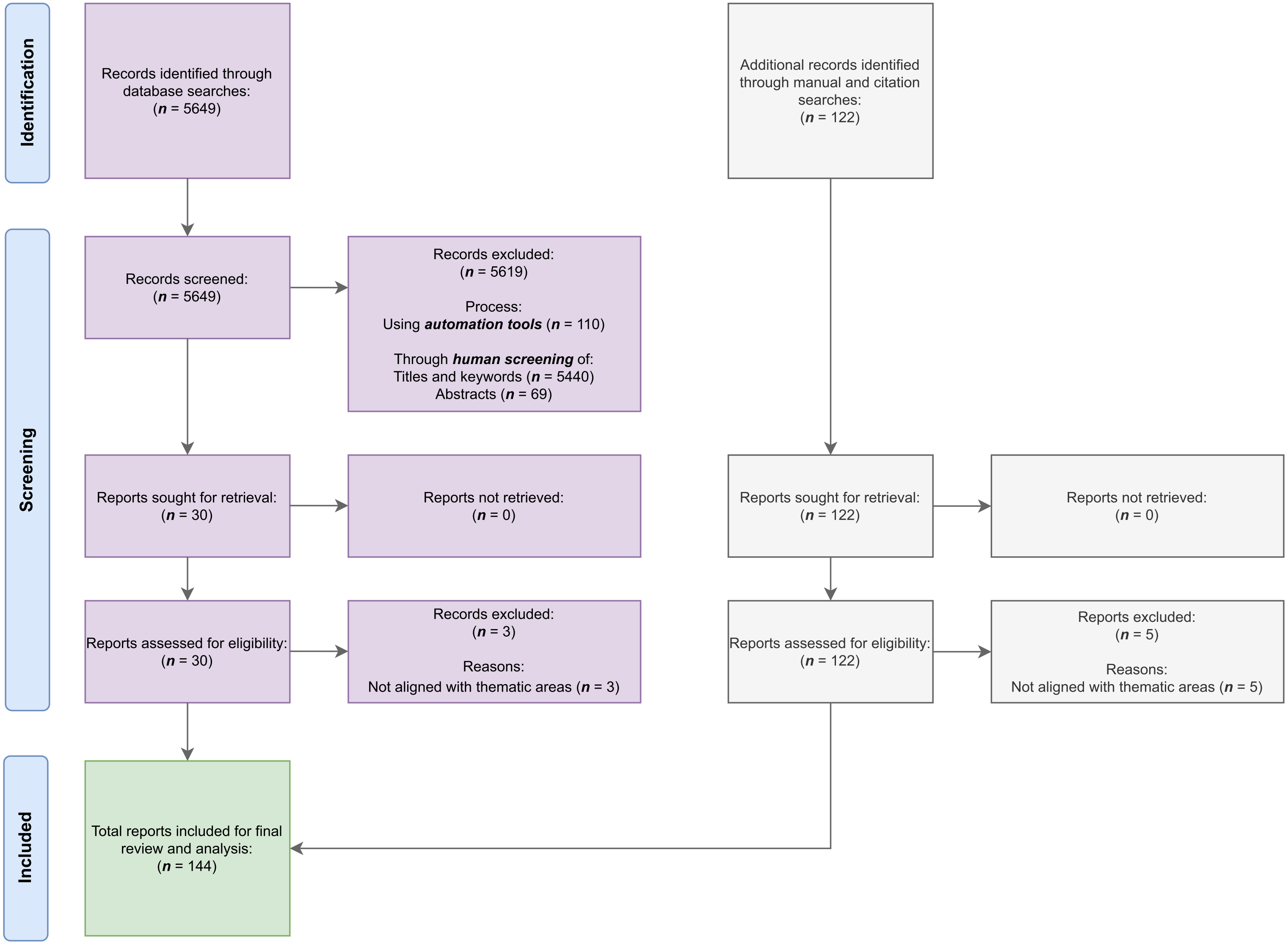

Fig. 2. PRISMA flow diagram for the identification, screening, and inclusion of articles for final review and analysis (Source: Adopted from Page et al. [15] and García-Peñalvo [16]).

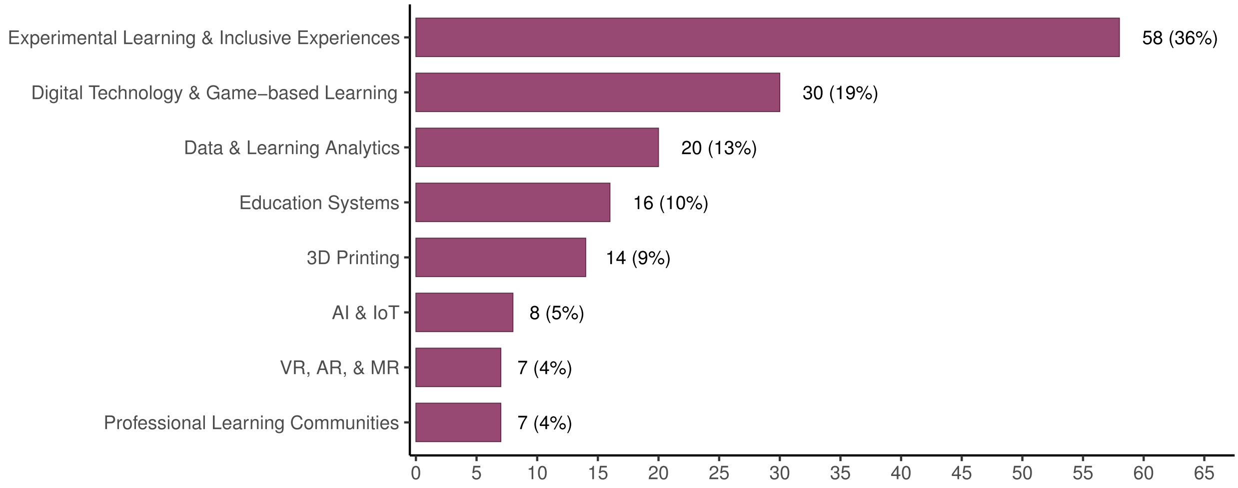

Fig. 3. Summary of focus areas across reviewed articles (Source: the authors).

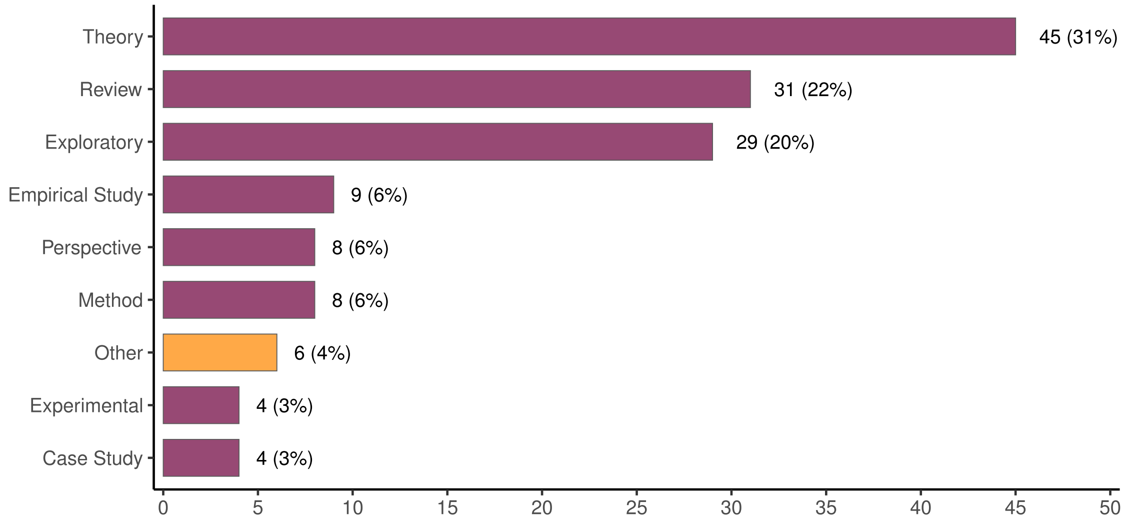

Fig. 4. Summary of article type across reviewed articles ($n = 144$; Source: the authors).

make education accessible to all, an alternative to the 'brick-and-mortar' approach is a necessity. The education system is mediocre in comparison to those of other developing nations, yet the quality of education is pivotal in the production of human capital [17,18]. Furthermore, the provision of education in South Africa is concentrated on physical access, notwithstanding the limited resources and enabling infrastructure available to teachers and learners. Currently, schools are characterised by poor infrastructure, overcrowded classrooms, and limited learning resources, thus making it difficult for teachers to conduct lessons [18]. Consequently, teachers find themselves assuming a multitude of roles (which may include being building technicians, learner counsellors, and learning resources developers) over and above their primary role of being education practitioners. This places a huge challenge on both their professional practice and their ability to complete the set curriculum. Hence, the deployment and unhindered availability of enabling infrastructure is important to support teaching and learning, which will ultimately lead to realising the desired outcomes.

The national lockdown in 2020, which came about as a result of governmental interventions to curb the spread of the coronavirus disease 2019 (COVID-19) pandemic, imposed restrictions on the movement of people, and enforced social distancing. This forced people to make a transition from familiar patterns of social behaviour to innovative ways of engaging and interactivity. While others were reluctant, especially in the education sector, the pandemic forced them to comply with the transition and break from traditional face-to-face practices. During this period, the national infrastructural gap in general was unequivocally exposed, and more specifically within the education system. In response, the government (through the head of state) undertook an ambitious infrastructure investment initiative to unlock and ignite the economy [19]. For the education system however, the infrastructural gap is huge. This warrants a practical shift in focus away from the age-old approach of deploying 'brick-and-mortar' infrastructure (which is arguably expensive) and instead to explore long overdue alternative approaches to accessing education.

Notwithstanding the digital skills gap amongst educators, as well as the limited human capital development, digitalisation became central in sustaining economic and education activities, thereby limiting any potentially adverse consequences that might have otherwise resulted from the national lockdown. The COVID-19 pandemic caused widespread disruption to schooling [20–22], and according to Mefi and Asoba [23, p. 1], it was "a direct threat to human resources with indirect consequences to all other elements of an organization". While recognising the contextual factors in South Africa as an unequal society, with schools lacking resources and students geographically dispersed, the need to serve them with inclusive educational opportunities is much greater. The COVID-19 pandemic provided us with an opportunity to ask questions such as: *Which societal challenges can be addressed through digitally enabled education?*

The advent and rapid growth of digital technologies has allowed for different entry points to education, and supports self-regulated learning. For instance, massive open online courses (MOOCs) have demonstrated a new and novel approach to teaching and learning for the education sector and beyond, providing multiple pathways to learning. MOOCs have proven to be an affordable and flexible way to deliver quality education at scale [24]. Such internet-driven learning platforms signify progress in technological developments and afford "dynamic engagement of hundreds to thousands of students" [25, p. 123]. The emerging technologies provide alternatives to the expensive and rigid education taking place in dedicated 'brick-and-mortar' spaces. The transition from traditional face-to-face classrooms to web-based course offerings is chiefly driven by internet access. Fortunately, technology is not replacing teachers because the web-based classrooms are still facilitated by teachers who teach the subjects' content. Furthermore, this is happening in a distributed teaching and learning environment, with no physical boundaries. The transition to online learning environments also means that there are copious amounts of learning data being generated. This data can be used "to evaluate, diagnose and regulate learning behavioural engagement of students" [26, p. 2207]. In distributed learning environments, there are multiple representations of subject matter content and expansion of existing structures of participation to enrich the teaching and learning process [27]. Participants in a distributed learning environment bring multiple perspectives and get multiple opportunities to engage and reflect on different perspectives.

4. Digital technologies in learning environments

The introduction of digital technologies into the learning environment has resulted in a paradigm shift that has transformed the education sector for the better. These technologies are broadly used by both teachers and learners to provide new learning experiences within the classroom and beyond. Furthermore, they are continually being improved upon in order to keep up with the changing nature of educational requirements [28]. In developing countries like South Africa, this is evident, as more schools ranging from public to private are being resourced with computer labs and smart devices to aid in the development of learners' digital literacy [29–31]. As digital disruption continues to reshape the education sector, the need for digital skills is significant to leverage digitalisation affordances to align with the eight technology constructs [32]. These constructs are: "responsiveness, equity, processing data, social connecting, podcasting, virtual connecting, multimodal, and integrated writing" (p. 1). To date, new educational platforms are being developed for various smart devices by various ICT specialists and organisations adopting a distributed education approach. However, according to [33] the "prevalence and adoption of Information and Communication Technology tools in education has often been guided by utopian perspectives without proper research to understand the schooling context and teachers' ICT development needs" (p. 17).

Education inequity is South Africa's biggest nightmare as it slows skills development and economic growth. In 2020, the COVID-19 pandemic made achieving educational equity even more challenging because inequities were made visible [34,20]. According to Hopwood [34], "[l]earning is socially constructed, influenced by the norms of the learning environment as well as the relationships within it" (p. 1). All schools and universities strived for academic continuity at the expense of interactivity to develop peer-to-peer relationships, teacher-to-learner relationships, and learner-to-content engagements [34,20]. Therefore, the affordances of the various technologies became paramount through the sociocultural lens to optimise interactions and enable meaningful engagement. Quinlan [35] asserted that learning is relational in nature, hence the importance of optimising the interactional opportunities that was disrupted by the pandemic.

When considering the social and relational nature of teaching and learning, we began to interrogate the potential of digital technologies to unlock online teaching and learning. Integrating smart digital technologies with the discourse of teaching and learning enriched the cognitive development process. Digital technologies were being used at various phases of schooling from early childhood development [36] right through to adult education [37]. While some believe that these technologies provide benefits for the education spaces within which they are deployed [38–40], others believe that there are also resultant risks [41,42]. More and more debates are currently taking place to provide clarity on the impact and effectiveness of using digital technologies for teaching and learning [43,44].

Fig. 5 provides the pictorial representation of the revolution and trends in digital technologies and our interest is mainly focused on the 2020s and beyond. However, throughout the other periods there is evidence of innovation. During the transition to emergency remote teaching (ERT), digital learning platforms played an important role as tools supporting distributive cognition, synchronous teaching, communication, and storing digital learning resources for asynchronous access [45,46]. The evolution of digital technologies, as illustrated in Fig. 5, has transformed from: (i) pre-digital technologies (such as film, radio, and television); to (ii) digital technologies (such as the personal computer); to (iii) connected digital technologies (facilitated by the internet); to (iv) niche and emerging technologies (such as the Internet of Things (IoT), 3D printing, big data and analytics, artificial intelligence (AI), and virtual/augmented/mixed reality). There are various enablers that have triggered the advancement and development of these technologies, such as:

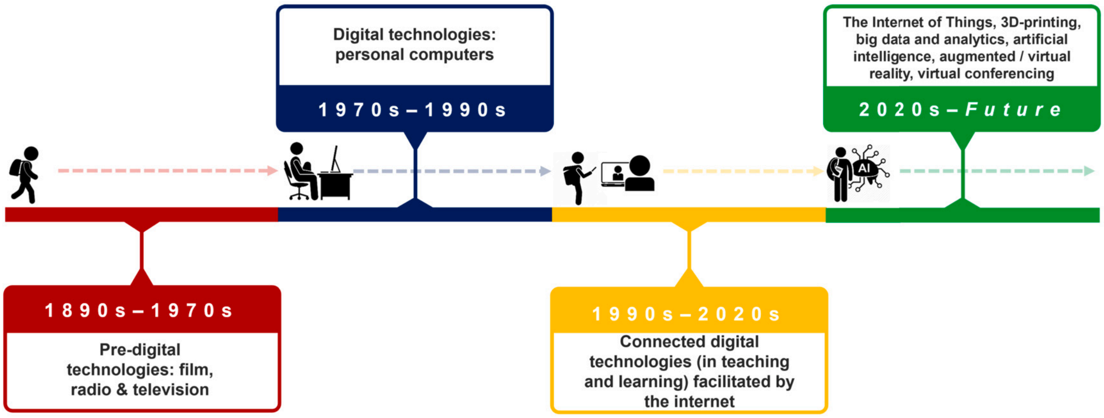

Fig. 5. Evolution and trends in digital technologies (Source: the authors).

(i) contextual challenges that have necessitated the adoption of smart digital technologies in education to address societal issues;
(ii) potential opportunities that can be unlocked by integrating smart digital technologies with the discourse of teaching and learning;
(iii) the likely adoption of these opportunities to enhance students' understanding and improve academic achievement; as well as
(iv) the prospects of creating and supporting an ecosystem of ubiquitous, quality, affordable and accessible education.

Recent studies in education have demonstrated that using apps and game-based learning on internet-enabled mobile devices can assist learners to build cognitive, arithmetic, language, creativity, and literacy skills [47–49]. Notwithstanding, there is also a prevalent view that the cognitive functions of the new generation of learners are vastly different from those of earlier generations [50]. Hence, there is a need to come up with more innovative approaches of integrating the use of traditional and digital technologies in education to provide more pleasant learning experiences. Ng [51] deliberates that educators must be aware of the many forms of technology accessible for teaching and learning, as well as their enabling capabilities, in order to create more engaged learning environments and experiences for learners. To this effect, research has demonstrated that it is the shift in teaching practices towards employing digital technologies that leads to gains in learning, and not so much the actual technology itself. Having said that, there are still people who are opposed or resistant to the use of digital devices in the classroom [52], while others harness the advantages that come with it.

The use of chalkboards in classrooms was first introduced in 1890, followed by the introduction of pencils in 1900. These were regarded as innovative visualisation tools for presenting subject content [53]. From this period, it became evident that increased use of educational technologies was essential to transform the teaching and learning spaces. The 1920s saw the introduction of the radio, which quickly became an instrument of mass media [54]. Surprisingly, radio continues to play an important role in the field of education, for remote education in particular, even after more than a century of its existence, and despite amazing breakthroughs in the world of ICT. In 1930, the overhead projector was introduced [55,56], followed by the ballpoint pen in 1940 [57]. The introduction of these technologies provided a new paradigm of learning. For instance, the overhead projector made it simple for educators to project pages and transcripts based on subject matter, and assisted in providing feedback for specific topics discussed in the classroom.

Meanwhile, the introduction of videotapes in 1951 provided an innovative medium which allowed learners to understand specific topics better compared with the use of textbooks [58]. This was because videos allowed learners to form a personal connection that they were unlikely to discover in any text, no matter how well written it was. The Skinner Teaching Machine (introduced in 1957) created a teaching and testing system that reinforced correct responses, and served as a basis for many technologies that are still used in teaching and learning today [59]. The photocopier (1959) and portable calculator (1972) were the next devices to make their way into classrooms, allowing for on-the-fly bulk production of materials and rapid mathematical computations. Michael Sokolski invented the Scantron testing technology in 1972, which allowed instructors to evaluate examinations more swiftly and efficiently [28].

In the early 1990s, the then Xerox PARC brought interactive whiteboards (IWBs) onto the market to be used in office settings. This technology was quickly adopted by other companies, including SMART Technologies, which extended the utility of this technology into other sectors. Today, SMART Technologies is one of the leading players in educational interactive boards and displays. Also in the early 1990s, Apple produced the first handheld personal computer, popularly known as a personal digital assistant (PDA). From then on, computers became a part of everyday life. The internet, which became public in 1993, became a massive electronic repository of knowledge, allowing for both research and education activities with a single mouse-click. Towards the late 1990s, the learning management system (LMS), in its current and familiar form, was brought to market as part of the broader e-learning revolution [60].

The rapid expansion of social media platforms for teaching and learning purposes, most prominent during the 2020s, played a role in the education space. This was chiefly because of new developments in technology, and the wider availability of internet access complemented by access to mobile phones [61]. This period saw the introduction of MySpace in 2003, Facebook in 2004, and Twitter in 2007, all of which drastically transformed the communication and education sectors. Instant communication evolved from a personal communication tool to a platform for educational training and outreach.

The period beyond the 2020s is markedly different from previous ones. It is characterised by the overwhelming adoption of niche and emerging smart digital technologies which collectively drive the 4IR era. These technologies, which include the IoT [62,63], 3D printing [64,65], big data [66–68], blockchain [69,70], AI [71,72], virtual reality (AR), augmented reality (VR), and mixed reality (MR) [73–78], as well as virtual conferencing [79–81], are speedily finding applications in the next generation of classrooms and learning spaces.

As a result, operating in this new era of smart digital technology will necessitate a considerably higher degree of thinking and cognitive skills from both learners and educators. The next section expands further on the utility of these smart digital technologies, discusses the pedagogical affordances of these technologies, and draws suggestions as to how they can be used to enhance teaching and learning experiences.

5. The utility of smart digital technologies in teaching and learning

Digital technologies, when used appropriately, offer innumerable benefits to the students as they allow for the fast-tracking of the learning process. For instance, they can serve as the hub for knowledge broadcasting and knowledge exchange, wherein information and knowledge flow freely not only from teachers to students, but also amongst students as well [82]. This is enabled by the continual growth of digital content and the vastness of digital tools which encourage the creation, consumption, management, and dissemination of knowledge [83,84]. The need to create and share knowledge in the context of education has long been established [85–89], and remains the cornerstone of a successful academic endeavour.

In facilitating this constant flux of information and knowledge, digital technologies embrace the role of being an effective pedagogical tool primed towards discovering and developing critical thinking [47]. Uribe-Enciso et al. [90] reflect on the importance of inculcating critical thinking, arguing that it is tightly bound to society and its development. At the same time, digital technologies also foster the reciprocal relationship between teachers and students. This thus places digital technologies at the centre of building and cultivating deeper cognitive structures.

The remainder of this section highlights and acknowledges the internet, IWBs, and LMSs as pioneering digital technologies which have influenced and shaped digital pedagogy. It then focuses on some of the emerging smart digital technologies born of the 4IR era, and relates their utility in the teaching and learning environments.

5.1. Internet as an enabler

The internet is a fundamental enabler of distributed cognition and all digital learning platforms [91]. However, according to the Internet World Stats,[1] global internet penetration is at 64.2%, while in South Africa the internet penetration rate is below this figure at 57.5%. This is problematic for a country that has long aspired to be an advanced information society [92]. The internet as a key driver of economic development already shapes and enhances teaching and learning in ideal countries. In accordance with constructivists' mosaic views "meaning is constructed in our minds as we interact with the physical, social, and mental worlds we inhabit" [91, p. 14]. Internet as an enabler holds promise for increasing access to education and the multilayered infrastructure of ubiquitous computing technologies and applications is built on the internet architecture.

This technology allows connections between smartphones and human beings to optimise education access and the availability digital learning platforms. Education is now experienced beyond physical spaces because of the internet, which allows educators to present the content of subjects in multiple ways to create an inclusive and transformative teaching and learning environment. The multimodal presentation of subjects' content enables interaction with the content and the corresponding construction of mental structures to develop knowledge and understanding.

5.2. Interactive whiteboards

The IWB is a "touch-sensitive digital display that works in combination with a computer and projector" [93, p. 115]. As pedagogical tools, IWBs can be used "for collaboration, improving student learning outcomes and streamlining lesson planning" [94, p. 213]. They allow learners to "explore their own ideas and share them with the class in a reflective discourse" [95, p. 726]. IWBs have multimodal features which are instrumental in enabling different content presentations, thus ensuring inclusivity and equitable collaboration in the classroom. Furthermore, they provide multiple entries to subject content, which facilitates "improved levels of collaboration, reasoning, and academic attainment" [96, p. 187]. The chalk and chalkboard in the classroom were characterised by passive teaching and learning; now, the new pedagogies promote interactivity and dialoguing, allowing participants to engage with other classmates' ideas critically and constructively. Dialogic teaching privileges discussion and dialogue, and it is supported by the following four principles [97, p. 66]:

(i) **collective**: teachers and students collaborate with each other to build knowledge and understanding;

[1] The statistics presented by the Internet World Stats are for 31 December 2021, as updated on 25 May 2022. These are accessible via: https://www.internetworldstats.com/stats1.htm.

(ii) **reciprocal**: teachers and students share responsibilities for the flow of discussion and consider alternative perspectives;
(iii) **supportive**: students voice their ideas freely within a constructive community and help each other to reach a common understanding; and
(iv) **cumulative**: teachers and students build on each other's ideas and chain them into a coherent line of inquiry.

The positioning of IWBs as pedagogical tools is underpinned by constructivist principles of learning whereby learners are active participants in the classroom and in their overall cognitive development. The dialogic engagement enabled by IWBs allows learners to be attentive while also providing constructive feedback and alternatives until an agreement is reached. This is an indication that knowledge is co-created and further developed amongst members of communities. This further develops presentation skills, engagement skills, and the production of quality teaching and learning resources.

5.3. Learning management systems

A LMS is an important educational innovation. Toland et al. [98] define LMSs as "web-based systems that use synchronous and asynchronous technologies for the purpose of delivering educational content and facilitating communication between course participants" (p. 222). LMSs as critical tools in teaching and learning "allow students to participate in virtual communities and allow them the opportunity to take ownership of their own learning in ways not constrained by time and space" [46, p. 54]. These systems provide "user-friendly platforms that saved instructors time by sparing them from the task of learning programming languages and setting up the programs" [99, p. 333]. The pedagogical affordances of LMSs are significant as they allow continuity beyond the traditional face-to-face classroom. However, in the absence of connectivity, internet access, and instructional design principles amongst educators, this tool can create systemic inequalities.

5.4. The IoT

In general, the IoT refers to networked devices that "generate, exchange and consume data with minimal human intervention" [100, p. 5]. The IoT enables ubiquitous connectivity, which in turn enables ubiquitous teaching and learning that is not bounded by physical spaces and time. As an ideal enabler, the IoT reduces the gap on knowledge access and participation in different discourses. Now, because of its ubiquitous nature, it further enables various interactions at different levels, and has the potential to support professional learning communities (PLCs). PLCs, as strategic constructs, support "a community of continuous learners" [101, p. vii]. This collective learning enhances teachers' professional practices and removes barriers to equal access to best practices in education. Through the IoT, distributive digital learning platforms have been designed, developed, and rolled out in schools and tertiary institutions. The pedagogical affordances of such platforms are many and notably include: (i) centrality in student communication; (ii) support for various interactions; (iii) repository for multimodal digital content; (iv) electronic assessments; (v) distributed teaching; and (vi) hosting virtual conferencing platforms.

Therefore, 'brick-and-mortar' education is complemented by the IoT technologies to supplement learning resources and allow teaching and learning beyond the 'walls of the classroom'. In addition, the ubiquitous nature of the IoT technologies optimises the three interactions [102] essential in teaching and learning, and operationalises the three presences critical in education [103]. These interactions are socially constructed and support epistemic engagement, and are conceptualised as: (i) student to student; (ii) student to content; and (iii) educator to student [102]. The three presences, which are crucial in promoting a "collaborative and worthwhile educational experience", are: (i) social presence; (ii) cognitive presence; and (iii) teacher presence [103, p. 6]. This enhances student learning of diverse content in multiple representations, and the dynamic technology-mediated representations have opened many domains for teaching and learning access. However, Dlamini and Ndzinisa [46, p. 53] point out that during the COVID-19 pandemic, "many lecturers have not been adequately prepared to transition to emergency remote teaching and do not have the necessary technological abilities". Therefore, the investments in digital technologies, especially digital learning platforms, must be matched with professional development opportunities for the education sector to pedagogically embrace such technologies. This aligns with Mentis [104, p. 217] that there ought to be a "reciprocal interaction between technology and pedagogical practices". With such dynamic technologies, there is no need for structures in education that promote homogeneity, and students must have multiple entries to knowledge.

5.5. 3D printing

With the growing interest in remote learning options, the incorporation of 3D printing technologies in teaching and learning activities has emerged as a popular solution. As 3D printers (and their associated technology) have become more affordable, schools and tertiary institutions are embracing this technology as a useful tool that has the potential to bridge the physical and digital divide. Over the years, this technology has assisted learners to develop 3D models of finished products, thus helping with the visualisation of such projects at different design phases. To date, the application of 3D printing spans a variety of subjects, including:

(i) science [105];
(ii) graphic design [106];
(iii) engineering education [107,108];
(iv) mathematics [109,110];

(v) biology [111];
(vi) history [112];
(vii) geography [113]; and
(viii) chemistry [114,115].

The utilisation of this technology encourages students to actively participate in classroom activities, rather than being passive consumers of knowledge. Furthermore, the technology itself plays a significant role in the conceptual, design, and implementation stages of projects. This means that students are provided an opportunity to gain the hands-on skills and experience required to develop finished products. This will enable new avenues of learning, where students can utilise this technology to translate the theory into practice. According to Sun and Li [116], the application of 3D printing technology will aid students to get rid of the fantasy of abstract concepts and knowledge, increase their thorough grasping of knowledge, and arouse their curiosity by transforming concepts and knowledge into three-dimensional representations.

5.6. Virtual, augmented and mixed reality

The rapid advancement in VR, AR, and MR technologies provides hybrid-user experiences where physical and virtual objects are integrated at different levels [77]. Verhey et al. [73, p. 2] define these technologies in the following manner:

(i) VR is a “technology that visually immerses the user in a completely artificial, computer-generated environment”;
(ii) AR is a “digital display overlay on real-world surfaces, allowing for depth perception”; and
(iii) MR is a “digital display overlay combined with interactive projected holograms”.

The potential of these technologies is to produce new experiences in the classroom environment by integrating “technological (embodiment), psychological (presence), and behavioral (interactivity)” [77, p. 547] perspectives to enable smart education and influence learners’ engagement in the classroom. Examples of VR technologies are head-mounted displays (HMDs) such as Oculus; whereas AR technologies include Google Glass, Epson SmartGlasses, Microsoft HoloLens, and Microsoft HoloLens 2; and examples of MR are Fragments, HoloAnatomy, RoboRaid, and ZARZL.

The merging of the real and the virtual worlds offers the education sector a passively entertaining educational experience [74]. The combination of VR, AR, and MR manifests results in technology-enhanced classroom experiences, especially in the learning of difficult concepts and experimenting with dangerous chemicals in the virtual worlds. The intersection of virtual and physical realities in VR, AR, and MR provides “a level of immersion greater than desktop immersion” [74, p. 233]. The interplay between these immersive technologies and game-based learning has the potential of helping learners develop better conceptual understanding of key concepts (such as chemical reactions or molecular visualisations) while also reducing mental load and enhancing learners’ attainment.

5.7. Virtual conferencing technologies

Virtual conferencing has become an integral part of teaching and learning [79,80]. The COVID-19 pandemic put pressure on educational institutions to adopt innovative approaches to education [46,22]. Dash et al. [117] present a review of some of the platforms that have become prominent in the education space, largely due to the COVID-19 pandemic. Within this context, virtual conferencing technologies have become central to teaching and learning because of the discernible benefits these technologies bring to distributive cognition. The key pedagogical advantages of virtual conferencing technologies are ubiquity and dynamic educational interaction (student to student, students to content, and educator to students). The virtual conferencing tools are internet-based, allowing verbal presentations, multimodal content display, and breakaway sessions. The emphasis is on the various forms of presence and interactions, enabling diverse perspectives to be shared and debated beyond physical structures. Vygotsky [11, p. 57] proposed that higher levels of functioning are based on interactions:

> Every function in the child’s cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (interpsychological) and then inside the child (intrapsychological). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relations between human individuals.

Therefore, virtual conferencing tools are an enabler, and allow participants to share and collaborate while distributed in different contexts. Outside of the physical structures, virtual conferencing technologies, along with digital devices, enable innovative and inclusive teaching and learning through the various forms of content such as speech, voice recordings, texts, images, videos, and slide presentations. Virtual conferencing technologies have the potential to revolutionise how knowledge is constructed and enrich the various presences as reported by [103]. The pedagogical affordance of virtual conferencing technologies—synchronous interaction—enhances participation and educational experience.

5.8. Applications of blockchain and AI

Technologies such as blockchain and AI are steadily finding their way into education, and such proliferation is expected to drive changes in the education system [69,70]. These technologies have brought about endless opportunities in education and have also seen applications in the automation of common teaching and learning tasks. For instance, the continual adoption of AI will be critical in addressing repetitive tasks that educators undertake on daily basis, some of which include: (i) grading of learner assessments; (ii) compiling various reports; (iii) preparing teaching and learning materials; as well as (iv) undertaking other administrative tasks. This will assist in relieving educators of the often burdensome non-teaching activities, thus allowing them to focus on their core teaching duties.

The application of AI will also drive personalised and self-paced learning by placing emphasis on the individual requirements of learners [118,119]. This will be achieved by identifying particular subject matter content that learners are struggling with, and using that to make informed decisions about content to be repeated in the course. This means that assistance can be tailored towards subject content that is of great concern to learners rather than that which they are already competent in. In another instance, through the advanced use of natural language processing (NLP), an application area of AI, there is now potential to assist learners who are non-native speakers (or who are otherwise disadvantaged) and may be struggling with teachers' accents. These learners could now have access to real-time subtitles of a lesson as it takes place. Indeed, this illustrates how the concepts and technologies of the 4IR era are attuned to work in concert. To this effect, AI is viewed a potential tool that will address the barriers of traditional 'brick-and-mortar' education system.

5.9. Big data and learning analytics

The evolution of data and its related analytics offers potential benefits to both educators and learners in terms of improving teaching and learning practices. There is clear evidence that education is gradually shifting away from a one-size-fits-all approach towards precision education that is tailored towards the needs of learners from diverse backgrounds [120,121]. This implies that educational specialists and policymakers must embrace data-driven/informed/based decision-making (DDDM/DIDM/DBDM)[2] methods which are crucial for enhancing pedagogical approaches that are customised to accommodate learners' individual needs and demands [122–124]. This will facilitate the adoption of these decision-making techniques through customised, self-directed, and self-paced learning experiences that will assist teachers with planning and orchestration [125]. In this context, teachers are already deploying flavours of learning analytics practices to: (i) discover topics that are complex for learners; (ii) identify specific requirements for individual learners; as well as (iii) come up with inclusive pedagogical approaches that will enable personalised learning experiences. For instance, Thille and Zimmaro [126] demonstrate the use of an open learning analytics platform to enhance learning and ascertain the collaboration between teachers and learners using evidence-based decision-making. Mavroudi and Papadakis [127] showcase how teachers make use of big data analytics to address teaching and learning concerns in classrooms as well as to undertake some administrative duties. Even though data has been successfully used in education to yield positive results, Agasisti and Bowers [128] warn of the drawbacks of insufficient analytics in education, as well as a variety of factors that impede data utilisation. As a result, there is still a need for data specialists who will continue to reinforce the positive data-driven/informed/based strategies required to enhance education.

6. The intersection of people, technology, and data to improve education

Effective integration of smart digital technology and tools into teaching and learning requires a complex and robust interaction between people, technology, and data. This interaction manifests unique learning opportunities that were previously not possible. The use of these tools and approaches further opens up channels of communication, which are both synchronous and asynchronous, tailored towards improving learners' cognitive development and their overall learning experience. As people (teachers, learners, administrators, and other key stakeholders) embrace the use of smart digital technology tools and approaches, as guided by their associated affordances, the result is not only a harmonious and highly energised teaching and learning environment, but also a rich collection of data that are produced in the process.

The intersection of the internet, LMSs, and IWBs enables the production of quality teaching and learning resources that are accessible and inclusive. This intersection allows access to data that can be used to improve both the learning practices and the ways learners are supported in their education journey. The implementation of learning analytics gives access to learners and the learning environment. This can be used to "access, elicit, and analyse them for modelling, prediction, and optimization of learning processes" [129, p. 288]. In addition, large datasets have become available on how learners interface with IWBs and their performance can be managed through the LMS in real-time. These technologies bridge the technical, pedagogical, and social domains to ensure that learners' needs are attended to timeously and in the process support the multiple dimensions of human development.

Data use in the education system has gained increasing importance as a basis upon which to make many decisions ranging from those pertaining school improvement to those at the core of classroom and instructional discourse. Therefore, schools need to develop a data-friendly culture as teachers and administrators seek reliable data to inform their decisions about curriculum and

[2] The terms DDDM, DIDM, and DBDM are construed to be similar for the purposes of the arguments presented in this paper. Where DDDM is used, the other two are implied.

instruction. Thus, in order to use data effectively in schools, we must be intentional about creating the right culture around it. Fostering such an atmosphere is a gradual process [130] which, if embraced, yields impressive progress. In the recent past, data from standardised testing[3] on a global scale have been used to measure the success of students, teachers, and schools—and even to mark global competitiveness (or lack thereof) at a country level. According to Henderson and Powers [131], data in schools can improve the return on investment (ROI) especially on learning resources, technology investments, and the development of best practices.

Developments in technology, and the advent of data and learning analytics, offer enormous opportunities to improve education systems the world over; however, the fast pace and scale of change pose challenges and risks that must be addressed to embrace the utility of data in education. The ability to use data to track performance is as valuable for educators as it is for commercial organisations adjusting their sales strategy based on the analysis of customer behaviour, to hospitals evaluating their treatment effectiveness, and teachers adapting their instruction to well-defined learners' needs [132]. Analysed data enable teachers to be more effective and proactive—reaching out before a final exam, for instance—instead of after a learner fails. The use of data in education is in multiple folds: (i) making use of multitude strategies to analyse data to propel teaching and learning; (ii) making use of technology to support the use of data; (iii) making use of data to support the use of technology; (iv) making use of data to engage the broader school community (teachers, parents, learners, sponsors, and so on); as well as (v) making use of data to analyse strengths, weaknesses, opportunities, and threats for school improvement. There is increasing interest in using data for fostering and tracking accountability amongst school leaders and teachers, thus holding them accountable for the quality of the education they provide [132]. Indeed, data can be used as a compelling force in improving schools. However, there is a growing recognition that data should not only be used for compliance and accountability, but also for continuous improvement in schools [133,134].

Maintaining and using data effectively in the education system has been a struggle for many institutions [135–138]. DDDM (including DIDM and DBDM), which entails gathering data to understand whether or not a school is meeting its purpose and vision, requires a cultural shift in thinking that must be nurtured by all stakeholders, and they should be committed to this effort. Stakeholders who use data productively have a mindset of overseeing their own destiny, always needing to know more, and creating or locating the knowledge that will be useful to improve the institution. Certainly, there is considerable evidence that using data can be the impetus for conscious attention to educational issues that might not have been considered without them [139]. However, Marsh et al. [140] caution that DDDM does not guarantee effective decision-making: having data does not mean that it will be used appropriately or lead to school improvements. Although only a few studies provide empirical evidence of the effect of DDDM on student achievement, there is considerable empirical evidence for the elements DDDM can be decomposed into, such as the impact of feedback, setting goals, and improving instructional quality [141]. These elements, in concert with the use of smart digital technology tools and approaches, are thus crucial in supporting various teaching and learning techniques.

Through leveraging these elements, DDDM can provide valuable insights into how these techniques are being used in the classroom, and how they can be adapted or modified to better meet the needs of learners. For instance, it has already been illustrated in earlier sections how techniques such as cooperative learning [9,10], dialogic teaching [97], and personalised and self-paced learning [118,119] can be enhanced through leveraging smart digital technology tools and approaches. Another such technique that can also enjoy the benefits of DDDM and the use smart digital technology tools and approaches is reciprocal teaching [142].

Reciprocal teaching refers to an instructional activity in which students become the teacher in small group reading sessions. Teachers model the discussion, then help students learn to guide group discussions using four strategies, which are: (i) summarising; (ii) question generating; (iii) clarifying; and (iv) predicting [142]. Once students have learned the strategies, they take turns assuming the role of the teacher in leading a dialogue about what has been modelled by the teacher. Then students experience supportive interactions with the teacher while their classmates view them more positively; similarly, positive peer relationships may engender cooperative participation in the classroom and improved teacher-learner interactions. Reciprocity that takes place in the classroom gives teachers the leverage they need to influence learners' behaviour and work habits, thereby making classroom management plans matter to them. It also allows teachers and learners to engage in a meaningful debate [143]. Teachers determine, in consultation with each other, what learners should learn and how, with what purpose in mind, and how their learning can be facilitated. This consultation is not just something that takes place before the start of the lesson but also during the lesson, which is characterised, according to Smith [144, p. 240], by the integration of "design and delivery of learning programs to meet the needs of different groups of learners". Reciprocity should not be interpreted here as a selfish and purely outcome-oriented preference, but rather as an equilibrium strategy in digital education that encourages effective collaborations in the classroom. Collaborative learning strategies, which involve learners working together to achieve academic objectives, have been identified to be promising classroom-based techniques [145,9,146,97].

It is important to note that although these techniques may not represent an exhaustive set of teaching and learning techniques in classroom settings, nor are they mutually exclusive, they share a common goal of promoting active engagement, a deeper understanding, and critical thinking amongst learners, albeit through different focus, methods, and strategies. In this sense, teaching and learning emerge as highly social activities, rooted in socio-constructivist ontology. Thus, interactions [102] and presences [103] are guided by, and mediated through, digital technology tools and approaches, and these in turn influence the cognitive and affective development of learners, and at the same time enable the co-construction of knowledge amongst learners. Through a distributed cognition lens, digital technology tools and approaches thus provide the materials and resources (that is, the "external resources") necessary for cognitive activity [147, p. 179].

[3] The TIMSS, PISA, and PIRLS are three popular standardised tests that are administered globally on a regular basis, primarily to monitor trends in student achievement.

7. Conclusion and future research direction

From ancient times where the boundaries of learning were restricted to 'brick-and-mortar' to today's digital era, the use of technology in classrooms has pushed capacities and competences amongst learners and educators to new heights. This study sought to explore and explicate the challenges, opportunities, and prospects of adopting and using smart digital technologies in learning environments guided by the four research questions it posed. Accordingly, adopting an iterative literature review approach through the theoretical and philosophical lens of complexity theory, one of the key revelations was that the use and continuous adoption of smart digital technologies in the education sector promises to generate more meaningful engagements while embracing various learning styles that will assist learners in demonstrating their cognitive skills and improve comprehension of the subject matter. The findings further revealed that the future of education is transiting towards more personalised and self-paced designs, thus allowing learners to advance progressively from comprehending simple to sophisticated topics. Additional insights drawn from answering the guiding research questions are presented in the subsequent section.

7.1. Insights from research questions

RQ1: What are the contextual challenges that have necessitated the adoption of smart digital technologies in education to address societal issues?

The 'brick-and-mortar' approach to education is limiting as it confines teaching and learning to physical spaces and face-to-face interaction. This approach is aligned with the treatment of learners as a homogeneous group instead of allowing learners and teachers to engage beyond the walls of the classroom to explore and investigate different curriculum topics. Thus, digital technologies stand to enable an inquiry-based approach to learning as well as differentiated instructions to avoid a one-size-fits-all approach. Differentiated instruction acknowledges the diversity of the learners in promoting each learner's development. The one-size-fits-all approach does not support the learners with different abilities, and so interactions [102] and presences [103] suffer the consequences.

In schools, the intersection of the internet, LMSs, and IWBs enables differentiated teaching and learning. Educational resources that are accessible beyond physical spaces are crucial in creating inclusive learning environments. These resources can increase the benefits of these learning environments in terms of scalability and accessibility. The diversity of learners also demands multimodal education resources and learning to unlock access to subject content and enhance learners' educational experience. The pedagogical affordance of digital technology is multimodal teaching, which fosters an inclusive approach through visual, kinesthetic, and auditory strategies. These strategies activate all the channels of presenting information so that learners experience a variety of content presentation.

RQ2: What are the potential opportunities that can be unlocked by integrating smart digital technologies with the discourse of teaching and learning?

It has been highlighted that schools, teachers, and government institutions will need to embrace the affordances that come with 4IR technologies, which present a potential to transform the education landscape as well as accelerate digitalisation in schools. Until recently, there have been ongoing debates on the merits of: formal and informal learning; or centralised and distributed teaching and learning; or 'traditional' and technology-supported teaching and learning. Now, there are pockets of growing evidence that technology (more specifically, smart digital technologies and associated approaches) have the potential of settling these debates and breaking down the silos that have supported these dichotomies.

The pedagogical integration of digital tools and approaches in education greatly enhances the channels of communication, both synchronous and asynchronous, thereby improving learners' engagement with content and elevating their overall learning experience. The ubiquity of technology fosters an open and inclusive learning environment, allowing for individualised instruction, and facilitating collaboration with peers globally. This collaborative approach is essential for uncovering alternative solutions to education challenges. Smart digital technologies enable learners to become more active and independent learners through knowledge-building communities enabled via web-based education and social platforms. In ubiquitous learning environments, learners become members of knowledge-building communities, with the opportunity to participate in a variety of modes of communication beyond just face-to-face interaction. These inclusive environments accommodate all learners, including introverts who may especially benefit from online interaction opportunities.

RQ3: How can these opportunities be adopted to enhance students' understanding and improve academic achievement?

This is possible with the fusion and holistic adoption of 4IR technologies such as the IoT, 3D printing, big data and learning analytics, blockchain, AI, as well as virtual conferencing. The integration of blockchain and AI, and the reinforcement of positive data-driven/informed/based methods, as seen through the lens of many authors in literature, plays a critical role in driving the necessary reforms in the system. Furthermore, the presence of IoT enables ubiquitous teaching and learning that is not bounded by physical spaces and time. This means that the gap on knowledge access and participation from different discourses can be possible. It is also evident that the rapid adoption of virtual conferencing provides a friendlier platform for schools, learners, and teachers to connect, collaborate, and encourage content sharing, while the use VR, AR, MR, and 3D printing in classrooms enables new avenues of learning, where students can utilise this technology to translate theory into practice.

RQ4: How can smart digital technologies support an ecosystem of ubiquitous, quality, affordable and accessible education?

This article has highlighted digitalisation affordances and discussed the impediments and complexities of digitally-enabled education. It further expanded on how digitalisation supports and promotes inclusive learning through meaningful data usage in order to gain insight into the overall performance at a high level (institution) and at a granular level (students). Moreover, it discussed the demise of the 'brick-and-mortar' monopoly in education, the evolution of smart digital technologies and related approaches, as well as prospects of utilising these technologies in classrooms. The development of ubiquitous learning environments provides learners with freedom to engage with content in an undisrupted and self-paced environment. In ubiquitous learning environments, teachers are already deploying flavours of learning analytics practices to: (i) discover topics that are complex for learners; (ii) identify specific requirements for individual learners; as well as (iii) come up with inclusive pedagogical approaches that will enable personalised learning experiences. Mavroudi and Papadakis [127] showcase how teachers make use of big data analytics to address teaching and learning concerns in classrooms as well as to undertake some administrative duties. This enables the move towards precision education that is tailored towards the needs of learners from diverse backgrounds [120,121]. The foregoing is budding evidence of how smart digital technologies and related approaches can serve to support a comprehensive ecosystem of accessible, quality, and affordable education, and indeed is a growing testament to their value.

7.2. Limitations

There were three main limitations that were observed during the undertaking of this review study.

The first limitation of this review study was the broad scope of its aim, which resulted in the identification of numerous smart digital technologies and approaches that aligned with the thematic areas of the study. This broad aim caused an abundance of information, making it challenging to provide an in-depth analysis of each technology and its associated approaches.

The second limitation was that the thoroughness of the review was limited by the lack of in-depth examination of the fundamental theoretical perspectives and implications related to the integration of each of the identified smart digital technologies and their approaches. The broad aim of the study, which led to the identification of multiple smart digital technologies and approaches, played a role in this limitation. To gain a richer and more comprehensive understanding, future studies could consider a more focused aim, such as delving into a specific technology and its approaches.

The third and final limitation was that the validity of the key findings of the review was partially limited due to the exclusive reliance on published reports for its analysis and synthesis. In order to add further context to these findings, and strengthen their practical implications, future studies could adopt a more diverse set of methodological approaches, such as conducting interviews and observations.

7.3. Future research direction

The advent of technological advancements has significantly impacted pedagogical practices and learning modalities, warranting a need for comprehensive research grounded on diverse theoretical perspectives. Thus, delving deeper into the interplay between technology and education appears to be a worthwhile pursuit. In this context, it is essential for researchers to undertake country-wide, large-scale investigations to identify evolving digitalisation opportunities in education. Additionally, researchers should adopt mixed or multi methodological approaches to generate inclusive perspectives on leveraging smart digital technologies in educational settings.

Significant disparities can often arise among technology, the learning environment, and educators. Therefore, understanding the interplay between these factors is crucial for ensuring sustainable advancements in smart digital education and promoting effective professional practices. Thus, for effective harnessing of smart digital technology affordances, the gradual transition and introduction of 4IR technologies such as those discussed in this article needs to be given due consideration. Admittedly, the on-boarding of these 4IR technologies in the education sector is still in its infancy, especially in developing countries.

Pursuing longitudinal research has important theoretical and practical implications in the uptake and positioning of technology in education to transform teaching and enhance learning. In this spirit, a comprehensive examination of digitalisation in education and an analysis of the digital ecosystem, including an exploration of opportunities, barriers, and successful cases, are necessary to gain a clear understanding of the potential advantages of using these technologies in classroom lessons. This is an essential undertaking in driving a future research agenda on the promises of smart digital technologies and their approaches in educational settings.

In sum, the digital education ecosystem needs to be studied in more depth in order to derive new patterns and explanations for smart digital education. This will yield several benefits. Firstly, it will enable the establishment of solid links amongst multiple actors in the education sector, as well as contribute to the development of new research and understanding of necessary policy interventions. Secondly, it will allow for deeper exploration of social inequalities and hierarchies that restrict the possibilities of smart digital technologies and their approaches in education. Lastly, it will encourage the use of quantitative approaches with large samples to sufficiently inform practice and develop new theories grounded on digitalisation perspectives in education.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

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.

Data availability

Data included in article/supp. material/referenced in article.

References

[1] K. Srivastava, S. Dey, Role of digital technology in teaching-learning process, IOSR J. Humanit. Soc. Sci. 23 (2018) 74–79, https://doi.org/10.9790/0837-2301057479.
[2] V. Prain, P. Cox, C. Deed, J. Dorman, D. Edwards, C. Farrelly, M. Keeffe, V. Lovejoy, L. Mow, P. Sellings, B. Waldrip, Z. Yager, Personalised learning: lessons to be learnt, Br. Educ. Res. J. 39 (2013) 654–676, https://doi.org/10.1080/01411926.2012.669747.
[3] M. Keppell, Personalised learning strategies for higher education, in: The Future of Learning and Teaching in Next Generation Learning Spaces, in: International Perspectives on Higher Education Research, vol. 12, Emerald Group Publishing, Limited, Bingley, 2014, pp. 3–21.
[4] L. Major, G.A. Francis, Technology-Supported Personalised Learning: A Rapid Evidence Review, Rapid Evidence Review 1, EdTech Hub, 2020, https://docs.edtechhub.org/lib/A2II5ZV7.
[5] J.G. Tullis, A.S. Benjamin, On the effectiveness of self-paced learning, J. Mem. Lang. 64 (2011) 109–118, https://doi.org/10.1016/j.jml.2010.11.002.
[6] M.-H. Cho, M.L. Heron, Self-regulated learning: the role of motivation, emotion, and use of learning strategies in students' learning experiences in a self-paced online mathematics course, Distance Education 36 (2015) 80–99, https://doi.org/10.1080/01587919.2015.1019963.
[7] L. Lin, K. Wang, D. Meng, W. Zuo, L. Zhang, Active self-paced learning for cost-effective and progressive face identification, IEEE Trans. Pattern Anal. Mach. Intell. 40 (2018) 7–19, https://doi.org/10.1109/tpami.2017.2652459.
[8] D. Meng, Q. Zhao, L. Jiang, A theoretical understanding of self-paced learning, Inf. Sci. 414 (2017) 319–328, https://doi.org/10.1016/j.ins.2017.05.043.
[9] D.W. Johnson, R.T. Johnson, An educational psychology success story: social interdependence theory and cooperative learning, Educ. Res. 38 (2009) 365–379, https://doi.org/10.3102/0013189x09339057.
[10] D.W. Johnson, R.T. Johnson, K.A. Smith, Cooperative learning: improving university instruction by basing practice on validated theory, J. Excell. Coll. Teach. 25 (2014) 85–118.
[11] L.S. Vygotsky, Mind in Society: The Development of Higher Psycological Processes, Harvard University Press, Cambridge, MA, 1978.
[12] M. Mason, Complexity theory and the philosophy of education, Educational Philos. Theory 40 (2008) 4–18, https://doi.org/10.1111/j.1469-5812.2007.00412.x.
[13] S.M. Manson, Simplifying complexity: a review of complexity theory, Geoforum 32 (2001) 405–414, https://doi.org/10.1016/s0016-7185(00)00035-x.
[14] G. Wisker, Developing doctoral authors: engaging with theoretical perspectives through the literature review, Innov. Education Teach. Int. 52 (2015) 64–74, https://doi.org/10.1080/14703297.2014.981841.
[15] M.J. Page, J.E. McKenzie, P.M. Bossuyt, I. Boutron, T.C. Hoffmann, C.D. Mulrow, L. Shamseer, J.M. Tetzlaff, E.A. Akl, S.E. Brennan, R. Chou, J. Glanville, J.M. Grimshaw, A. Hróbjartsson, M.M. Lalu, T. Li, E.W. Loder, E. Mayo-Wilson, S. McDonald, L.A. McGuinness, L.A. Stewart, J. Thomas, A.C. Tricco, V.A. Welch, P. Whiting, D. Moher, The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, BMJ 372 (71) (2021), https://doi.org/10.1136/bmj.n71.
[16] F.J. García-Peñalvo, Desarrollo de estados de la cuestión robustos: revisiones sistemáticas de literatura, Education Knowl. Soc. 23 (2022) e28600, https://doi.org/10.14201/eks.28600.
[17] N. Mouton, G. Louw, G. Strydom, Critical challenges of the South African school system, Int. Bus. Econ. Res. J. 12 (2012) 31–44, https://doi.org/10.19030/iber.v12i1.7510.
[18] M.W. Legotlo (Ed.), Challenges and Issues Facing the Education System in South Africa, Africa Institute of South Africa, Pretoria, South Africa, 2014.
[19] The Presidency, President Cyril Ramaphosa: 2022 State of the Nation Address, Online, 2022, https://www.gov.za/speeches/president-cyril-ramaphosa-2022-state-nation-address-10-feb-2022-0000. (Accessed 11 April 2022).
[20] N. Ndzinisa, R. Dlamini, Responsiveness vs. accessibility: pandemic-driven shift to remote teaching and online learning, High. Education Res. Dev. (2022) 1–16, https://doi.org/10.1080/07294360.2021.2019199.
[21] J. Gore, L. Fray, A. Miller, J. Harris, W. Taggart, The impact of COVID-19 on student learning in New South Wales primary schools: an empirical study, Aust. Educational Res. 48 (2021) 605–637, https://doi.org/10.1007/s13384-021-00436-w.
[22] T. Issa, P. Isaias, T. Issa, Guest editorial, Interact. Technol. Smart Education 18 (2021) 273–277, https://doi.org/10.1108/itse-09-2021-248.
[23] N.P. Mefi, S.N. Asoba, Sustainable human resource practices for organizational competitiveness post the COVID-19 pandemic, Acad. Entrepreneurship J. 27 (2021) 1–7.
[24] M.H. Baturay, An overview of the world of MOOCs, Proc., Soc. Behav. Sci. 174 (2015) 427–433, https://doi.org/10.1016/j.sbspro.2015.01.685.
[25] R.S. Adham, K.O. Lundqvist, MOOCs as a method of distance education in the Arab World – a review paper, Eur. J. Open, Distance E-Learning 18 (2015) 123–138, https://doi.org/10.1515/eurodl-2015-0009.
[26] G. Sun, S. Bin, Construction of learning behavioral engagement model for MOOCs platform based on data analysis, Educ. Sci.: Theory Pract. 18 (2018) 2206–2216, https://doi.org/10.12738/estp.2018.5.120.
[27] R. Dlamini, Interactivity, the heart and soul of effective learning: the interlink between Internet self-efficacy and the creation of an inclusive learning experience, South. Afr. J. High. Education 37 (2023) 77–92, https://doi.org/10.20853/37-2-5105.
[28] S.K. Howard, A. Mozejko, Considering the history of digital technologies in education, in: M. Henderson, G. Romeo (Eds.), Teaching and Digital Technologies: Big Issues and Critical Questions, Cambridge University Press, Port Melbourne, Australia, 2015, pp. 157–168.
[29] J. Mabila, M. Herselman, J. Van Biljon, Digital content and sustained use in integrating tablet technology into teaching in resource constrained environments in South Africa: educators' views, in: L. Stillman, T. Denison, M. Anwar (Eds.), 13th Prato CIRN Conference, Monash Centre, Prato, Italy, 2016, pp. 69–81.
[30] T.L. Lindell, Teachers' challenges and school digitalization: Exploring how teachers learn about technology integration to meet local teaching needs, Ph.D. thesis, KTH Royal Institute of Technology, Stockholm, Sweden, 2022.

[31] M.P. Nkadimeng, Implementation of blended learning in Sekhukhune District schools in Limpopo Province, South Africa, Ph.D. thesis, University of Limpopo, Faculty of Humanities, School of Education, Polokwane, South Africa, 2022.
[32] R. Dlamini, F. Nkambule, Information and communication technologies' pedagogical affordances in education, in: A. Tatnall (Ed.), Encyclopedia of Education and Information Technologies, Springer International Publishing, Cham, 2019, pp. 1–14.
[33] R. Dlamini, K. Mbatha, The discourse on ICT teacher professional development needs: the case of a South African teachers' union, Int. J. Education Dev. Using ICT 14 (2018) 17–37.
[34] I. Hopwood, Peerless? How students' experience of synchronous online teaching can disrupt the development of relationships to peers, teachers, subject and self, Res. Pract. Technol. Enhanc. Learn. 18 (2023) 1–17.
[35] K.M. Quinlan, How emotion matters in four key relationships in teaching and learning in higher education, Coll. Teach. 64 (2016) 101–111, https://doi.org/10.1080/87567555.2015.1088818.
[36] K. Murcia, C. Campbell, G. Aranda, Trends in early childhood education practice and professional learning with digital technologies, Pedagogika 68 (2018) 249–264, https://doi.org/10.14712/23362189.2018.858.
[37] A. Gegenfurtner, B. Schmidt-Hertha, P. Lewis, Digital technologies in training and adult education, Int. J. Train. Dev. 24 (2020) 1–4, https://doi.org/10.1111/ijtd.12172.
[38] D. Laurillard, Digital technologies and their role in achieving our ambitions for education, University of London, Institute of Education, London, 2008.
[39] V. Kryukov, A. Gorin, Digital technologies as education innovation at universities, Aust. Educational Comput. 32 (2017) 1–16.
[40] E.V. Frolova, T.M. Ryabova, O.V. Rogach, Digital technologies in education: problems and prospects for "Moscow Electronic School" project implementation, Eur. J. Contemp. Education 8 (2019) 779–789, https://doi.org/10.13187/ejced.2019.4.779.
[41] N.B. Strekalova, Risks of implementation of digital technologies into education, Vest. Samara Univ. Hist. Pedagog. Philol. 25 (2019) 84–88, https://doi.org/10.18287/2542-0445-2019-25-2-84-88.
[42] L. Hadlington, M.O. Scase, End-user frustrations and failures in digital technology: exploring the role of fear of missing out, Internet addiction and personality, Heliyon 4 (2018) e00872, https://doi.org/10.1016/j.heliyon.2018.e00872.
[43] J.D.M. Underwood, The impact of digital technology: a review of the evidence of the impact of digital technologies on formal education, Review Report, British Educational Communications and Technology Agency, Coventry, United Kingdom, 2009.
[44] M.I. Qureshi, N. Khan, H. Raza, A. Imran, F. Ismail, Digital technologies in education 4.0. Does it enhance the effectiveness of learning? A systematic literature review, Int. J. Interact. Mobile Technol. 15 (2021) 31–47, https://doi.org/10.3991/ijim.v15i04.20291.
[45] M.A.C. Bhakti, W. Wandy, A.N. Noviarini, Internet data consumption during synchronous teaching-from-home period at Sampoerna University, J. Sist. Komput. Informatika 3 (2022) 366–371, https://doi.org/10.30865/json.v3i4.4121.
[46] R. Dlamini, N. Ndzinisa, Universities trailing behind: unquestioned epistemological foundations constraining the transition to online instructional delivery and learning, South. Afr. J. High. Education 34 (2020) 52–64, https://doi.org/10.20853/34-6-4073.
[47] K. Jodoi, N. Takenaka, S. Uchida, S. Nakagawa, N. Inoue, Developing an active-learning app to improve critical thinking: item selection and gamification effects, Heliyon 7 (2021) e08256, https://doi.org/10.1016/j.heliyon.2021.e08256.
[48] M.M.K. Elsherbiny, R.H.H.A. Maamari, Game-based learning through mobile phone apps: effectively enhancing learning for social work students, J. Soc. Work Educ. 40 (2021) 315–332, https://doi.org/10.1080/02615479.2020.1737665.
[49] N. Behnamnia, A. Kamsin, M.A.B. Ismail, The landscape of research on the use of digital game-based learning apps to nurture creativity among young children: a review, Think. Ski. Creativity 37 (2020) 100666, https://doi.org/10.1016/j.tsc.2020.100666.
[50] D.A. Lisachenko, A.V. Barmasov, M.N. Bukina, E.N. Stankova, S.O. Vysotskaya, E.P. Zarochentseva, Best practices combining traditional and digital technologies in education, in: O. Gervasi, B. Murgante, S. Misra, G. Borruso, C.M. Torre, A.M.A. Rocha, D. Taniar, B.O. Apduhan, E. Stankova, A. Cuzzocrea (Eds.), Computational Science and Its Applications – ICCSA 2017, in: Lecture Notes in Computer Science, vol. 10408, Springer International Publishing, 2017, pp. 483–494.
[51] W. Ng, Affordances of new digital technologies in education, in: New Digital Technology in Education, Springer International Publishing, 2015, pp. 95–123.
[52] T. Berger, M. Thomas, Integrating digital technologies in education: a model for negotiating change and resistance to change, in: M. Thomas (Ed.), Digital Education, Palgrave Macmillan's Digital Education and Learning, Palgrave Macmillan US, New York, NY, 2011, pp. 101–119.
[53] J.A. Hennington, Innovate with the chalkboard, J. Bus. Educ. 54 (1978) 68–71, https://doi.org/10.1080/00219444.1978.10535577.
[54] C. Michel, Educational radio and television—their transfer to developing societies, in: R.M. Thomas, V.N. Kobayashi (Eds.), Educational Technology–Its Creation, Development and Cross-Cultural Transfer, Pergamon Press, Oxford, United Kingdom, 1987, pp. 125–142.
[55] D. Kolb, Introduction to overhead projector demonstrations, J. Chem. Educ. 64 (1987) 348–351, https://doi.org/10.1021/ed064p348.
[56] J. Raymond, The computerized overhead projector, Comput. Educ. 11 (1987) 181–195, https://doi.org/10.1016/0360-1315(87)90053-4.
[57] S. Tawney, An analysis of the ball point pen versus the pencil as a beginning handwriting instrument, Elem. Engl. 44 (1967) 59–61.
[58] G. Al Murshidi, Videotaped teaching and learning methodology – an experiential learning and action research approach, J. Int. Education Bus. 14 (2020) 144–158, https://doi.org/10.1108/jieb-05-2020-0041.
[59] B. Skinner, Teaching machines, Science 128 (1958) 969–977.
[60] B. Davis, C. Carmean, E.D. Wagner, The Evolution of the LMS: from Management to Learning, Research Report, The eLearning Guild, Santa Rosa, CA, 2009, https://www.learningguild.com/insights/137/the-evolution-of-the-lms-from-management-to-learning/.
[61] R. Faizi, A.E. Afia, R. Chiheb, Exploring the potential benefits of using social media in education, Int. J. Eng. Pedagog. 3 (2013) 50–53, https://doi.org/10.3991/ijep.v3i4.2836.
[62] D.D. Ramlowat, B.K. Pattanayak, Exploring the internet of things (IoT) in education: a review, in: S.C. Satapathy, V. Bhateja, R. Somanah, X.-S. Yang, R. Senkerik (Eds.), Advances in Intelligent Systems and Computing, vol. 863, Springer Singapore, Singapore, 2019, pp. 245–255.
[63] M. Al-Emran, S.I. Malik, M.N. Al-Kabi, A survey of Internet of things (IoT) in education: opportunities and challenges, in: A.E. Hassanien, R. Bhatnagar, N.E.M. Khalifa, M.H.N. Taha (Eds.), Toward Social Internet of Things (SIoT): Enabling Technologies, Architectures and Applications, in: Studies in Computational Intelligence, vol. 846, Springer International Publishing, Cham, Switzerland, 2020, pp. 197–209.
[64] S. Ford, T. Minshall, Invited review article: where and how 3d printing is used in teaching and education, Addit. Manuf. 25 (2019) 131–150, https://doi.org/10.1016/j.addma.2018.10.028.
[65] D. Assante, G.M. Cennamo, L. Placidi, 3D printing in education: an European perspective, in: A. Cardoso, G.R. Alves, T. Restivo (Eds.), 2020 IEEE Global Engineering Education Conference (EDUCON), IEEE, Porto, Portugal, 2020, pp. 1133–1138.
[66] Y. Wang, Big opportunities and big concerns of big data in education, TechTrends 60 (2016) 381–384, https://doi.org/10.1007/s11528-016-0072-1.
[67] B. Williamson, Big Data in Education: The Digital Future of Learning, Policy and Practice, SAGE Publications, Limited, London, United Kingdom, 2017.
[68] M.I. Baig, L. Shuib, E. Yadegaridehkordi, Big data in education: a state of the art, limitations, and future research directions, Int. J. Educ. Technol. Higher Educ. 17 (2020) 1–23, https://doi.org/10.1186/s41239-020-00223-0.
[69] H. Yumna, M.M. Khan, M. Ikram, S. Ilyas, Use of blockchain in education: a systematic literature review, in: N.T. Nguyen, F.L. Gaol, T.-P. Hong, B. Trawiński (Eds.), Intelligent Information and Database Systems, in: Lecture Notes in Computer Science, vol. 11432, Springer International Publishing, Cham, Switzerland, 2019, pp. 191–202.
[70] H. Sun, X. Wang, X. Wang, Application of blockchain technology in online education, Int. J. Emerg. Technol. Learn. 13 (2018) 252–259, https://doi.org/10.3991/ijet.v13i10.9455.

[71] B. Berendt, A. Littlejohn, M. Blakemore, AI in education: learner choice and fundamental rights, Learn. Media Technol. 45 (2020) 312–324, https://doi.org/10.1080/17439884.2020.1786399.

[72] F. Cruz-Jesus, M. Castelli, T. Oliveira, R. Mendes, C. Nunes, M. Sa-Velho, A. Rosa-Louro, Using artificial intelligence methods to assess academic achievement in public high schools of a European Union country, Heliyon 6 (2020) e04081, https://doi.org/10.1016/j.heliyon.2020.e04081.

[73] J.T. Verhey, J.M. Haglin, E.M. Verhey, D.E. Hartigan, Virtual, augmented, and mixed reality applications in orthopedic surgery, Int. J. Med. Robot. Comput. Assist. Surg. 16 (2020) e2067, https://doi.org/10.1002/rcs.2067.

[74] M.J. Maas, J.M. Hughes, Virtual, augmented and mixed reality in k–12 education: a review of the literature, Technol. Pedagog. Education 29 (2020) 231–249, https://doi.org/10.1080/1475939x.2020.1737210.

[75] J. Cabero-Almenara, J.M. Fernández-Batanero, J. Barroso-Osuna, Adoption of augmented reality technology by university students, Heliyon 5 (2019) e01597, https://doi.org/10.1016/j.heliyon.2019.e01597.

[76] R. Sánchez-Cabrero, Ó. Costa-Román, F.J. Pericacho-Gómez, M.Á. Novillo-López, A. Arigita-García, A. Barrientos-Fernández, Early virtual reality adopters in Spain: sociodemographic profile and interest in the use of virtual reality as a learning tool, Heliyon 5 (2019) e01338, https://doi.org/10.1016/j.heliyon.2019.e01338.

[77] C. Flavián, S. Ibáñez-Sánchez, C. Orús, The impact of virtual, augmented and mixed reality technologies on the customer experience, J. Bus. Res. 100 (2019) 547–560, https://doi.org/10.1016/j.jbusres.2018.10.050.

[78] H. Ardiny, E. Khanmirza, The role of AR and VR technologies in education developments: opportunities and challenges, in: 2018 6th RSI International Conference on Robotics and Mechatronics (IcRoM), IEEE, Tehran, Iran, 2018, pp. 482–487.

[79] D. Vervoort, J.A. Dearani, V.A. Starnes, V.H. Thourani, T.C. Nguyen, Brave new world: virtual conferencing and surgical education in the coronavirus disease 2019 era, J. Thorac. Cardiovasc. Surg. 161 (2021) 748–752, https://doi.org/10.1016/j.jtcvs.2020.07.094.

[80] J. Arquilla, M. Guzdial, Transitioning to distance learning and virtual conferencing, Commun. ACM 63 (2020) 10–11, https://doi.org/10.1145/3398386.

[81] J.R. Cox, Enhancing student interactions with the instructor and content using pen-based technology, YouTube videos, and virtual conferencing, Biochem. Mol. Biol. Education 39 (2011) 4–9, https://doi.org/10.1002/bmb.20443.

[82] M.I. Eid, I.M. Al-Jabri, Social networking, knowledge sharing, and student learning: the case of university students, Comput. Educ. 99 (2016) 14–27, https://doi.org/10.1016/j.compedu.2016.04.007.

[83] J. Gregson, J.M. Brownlee, R. Playforth, N. Bimbe, The Future of Knowledge Sharing in a Digital Age: Exploring Impacts and Policy Implications for Development, Evidence Report 125, Institute of Development Studies, Brighton, United Kingdom, 2015.

[84] E. Bouton, S.B. Tal, C.S. Asterhan, Students, social network technology and learning in higher education: visions of collaborative knowledge construction vs. the reality of knowledge sharing, Internet High. Educ. 49 (2021) 100787, https://doi.org/10.1016/j.iheduc.2020.100787.

[85] P.M. Maponya, Fostering the culture of knowledge sharing in higher education, South. Afr. J. High. Education 19 (2005) 900–911.

[86] O.E.M. Khalil, T. Shea, Knowledge sharing barriers and effectiveness at a higher education institution, Int. J. Nucl. Knowl. Manag. 8 (2012) 43–64, https://doi.org/10.4018/jkm.2012040103.

[87] D.P. Meher, N. Mahajan, An analytical study of use of knowledge sharing methods in education, in: 2018 International Conference on Current Trends Towards Converging Technologies (ICCTCT), IEEE, 2018, pp. 1–6.

[88] S. Chatterjee, N.P. Rana, Y.K. Dwivedi, Social media as a tool of knowledge sharing in academia: an empirical study using valance, instrumentality and expectancy (VIE) approach, J. Knowl. Manag. 24 (2020) 2531–2552, https://doi.org/10.1108/jkm-04-2020-0252.

[89] A. Iqbal, Innovation speed and quality in higher education institutions: the role of knowledge management enablers and knowledge sharing process, J. Knowl. Manag. 25 (2021) 2334–2360, https://doi.org/10.1108/jkm-07-2020-0546.

[90] O.L. Uribe-Enciso, D.S. Uribe-Enciso, M.D.P. Vargas-Daza, Pensamiento crítico y su importancia en la educación: algunas reflexiones [Critical thinking and its importance in education: some reflections], Rastros Rostros 19 (2017) 78–88, https://doi.org/10.16925/ra.v19i34.2144.

[91] K. Swan, A constructivist model for thinking about learning online, in: J.C.M. John R. Bourne (Ed.), Elements of Quality Online Education: Engaging Communities, in: Sloan-C Series, vol. 6, Sloan-C, Needham, MA, 2005, pp. 13–30.

[92] T.D. Oyedemi, Digital inequalities and implications for social inequalities: a study of Internet penetration amongst university students in South Africa, Telemat. Inform. 29 (2012) 302–313, https://doi.org/10.1016/j.tele.2011.12.001.

[93] Y. Shi, C. Peng, H.H. Yang, J. MacLeod, Examining interactive whiteboard-based instruction on the academic self-efficacy, academic press and achievement of college students, Open. Learn. J. Open, Distance e-Learn. 33 (2018) 115–130, https://doi.org/10.1080/02680513.2018.1454829.

[94] Y. Shi, Z. Yang, H.H. Yang, S. Liu, The impact of interactive whiteboards on education, in: X. Yu, R. Lienhart, Z.-J. Zha, Y. Liu, S. Satoh (Eds.), Proceedings of the 4th International Conference on Internet Multimedia Computing and Service, ICIMCS '12, ACM Press, Wuhan, Hubei, China, 2012, pp. 213–218.

[95] H. Tanner, S. Jones, S. Kennewell, G. Beauchamp, Interactive whole class teaching and interactive white boards, in: P. Clarkson, A. Downton, D. Gronn, M. Horne, A. McDonough, R. Pierce, A. Roche (Eds.), MERGA 28, vol. 1, Mathematics Education Research Group of Australasia Inc., MERGA Inc., Melbourne, Australia, 2005, pp. 720–727.

[96] N. Mercer, S. Hennessy, P. Warwick, Dialogue, thinking together and digital technology in the classroom: some educational implications of a continuing line of inquiry, Int. J. Educ. Res. 97 (2019) 187–199, https://doi.org/10.1016/j.ijer.2017.08.007.

[97] I.A.G. Wilkinson, A. Reznitskaya, K. Bourdage, J. Oyler, M. Glina, R. Drewry, M.-Y. Kim, K. Nelson, Toward a more dialogic pedagogy: changing teachers' beliefs and practices through professional development in language arts classrooms, Lang. Education 31 (2017) 65–82, https://doi.org/10.1080/09500782.2016.1230129.

[98] S. Toland, J. White, D. Mills, D.U. Bolliger, EFL instructors' perceptions of usefulness and ease of use of the LMS Manaba, JALT CALL J. 10 (2014) 221–236, https://doi.org/10.29140/jaltcall.v10n3.177.

[99] W.-K. Yu, Y.-C. Sun, Y.-J. Chang, When technology speaks language: an evaluation of course management systems used in a language learning context, ReCALL 22 (2010) 332–355, https://doi.org/10.1017/s0958344010000194.

[100] K. Rose, S. Eldridge, L. Chapin, The Internet of Things (IoT): an Overview, Technical Report, The Internet Society (ISOC), Geneva, Switzerland, 2015, https://www.internetsociety.org/resources/doc/2015/iot-overview/.

[101] J.B. Huffman, K.K. Hipp, Reculturing Schools as Professional Learning Communities, R&L Education, Lanham, Maryland, 2003.

[102] T. Anderson, Modes of interaction in distance education: recent developments and research questions, in: M.G. Moore, W.G. Anderson (Eds.), Handbook of Distance Learning, Lawrence Erlbaum Associates, Inc., Mahwah, New Jersey, 2003, pp. 129–144.

[103] D.R. Garrison, T. Anderson, W. Archer, The first decade of the community of inquiry framework: a retrospective, Internet High. Educ. 13 (2010) 5–9, https://doi.org/10.1016/j.iheduc.2009.10.003.

[104] M. Mentis, Navigating the e-learning terrain: aligning technology, pedagogy and context, Electron. J. e-Learn. 6 (2008) 217–226.

[105] E. Canessa, C. Fonda, M. Zennaro (Eds.), Low-Cost 3D Printing for Science, Education and Sustainable Development, ICTP—The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy, 2013.

[106] P. Katsioloudis, M. Jones, Using computer-aided design software and 3D printers to improve spatial visualization, Technol. Eng. Teach. 74 (2015) 14–20.

[107] R.L. Martin, N.S. Bowden, C. Merrill, 3D printing in technology and engineering education, Technol. Eng. Teach. 73 (2014) 30–35.

[108] A. Eslahi, D.R. Chadeesingh, C. Foreman, E. Alpay, 3D printers in engineering education, in: K. Gravett, N. Yakovchuk, I.M. Kinchin (Eds.), Enhancing Student-Centred Teaching in Higher Education, Palgrave Macmillan, Cham, Switzerland, 2020, pp. 97–112.

[109] O. Knill, E. Slavkovsky, Illustrating mathematics using 3D printers, https://doi.org/10.48550/ARXIV.1306.5599, 2013.

[110] M. Huleihil, 3D printing technology as innovative tool for math and geometry teaching applications, IOP Conf. Ser., Mater. Sci. Eng. 164 (2017) 012023, https://doi.org/10.1088/1757-899x/164/1/012023.
[111] A.K. Hansen, T.R. Langdon, L.W. Mendrin, K. Peters, J. Ramos, D.D. Lent, Exploring the potential of 3D-printing in biological education: a review of the literature, Integr. Comp. Biol. 60 (2020) 896–905, https://doi.org/10.1093/icb/icaa100.
[112] R. Maloy, T. Trust, S. Kommers, A. Malinowski, I. LaRoche, 3D modeling and printing in history/social studies classrooms: initial lessons and insights, Contemp. Issues Technol. Teach. Education 17 (2017) 229–249.
[113] C. Oswald, C. Rinner, A. Robinson, Applications of 3D printing in physical geography education and urban visualization, Cartogr. Int. J. Geogr. Inf. Geovisualization 54 (2019) 278–287, https://doi.org/10.3138/cart.54.4.2018-0007.
[114] O.A.H. Jones, M.J.S. Spencer, A simplified method for the 3D printing of molecular models for chemical education, J. Chem. Educ. 95 (2018) 88–96, https://doi.org/10.1021/acs.jchemed.7b00533.
[115] C.W. Pinger, M.K. Geiger, D.M. Spence, Applications of 3D-printing for improving chemistry education, J. Chem. Educ. 97 (2020) 112–117, https://doi.org/10.1021/acs.jchemed.9b00588.
[116] Y. Sun, Q. Li, The application of 3D printing in mathematics education, in: 2017 12th International Conference on Computer Science and Education (ICCSE), IEEE, Houston, TX, USA, 2017, pp. 47–50.
[117] S. Dash, S. Samadder, A. Srivastava, R. Meena, P. Ranjan, Review of online teaching platforms in the current period of COVID-19 pandemic, Indian J. Surg. 84 (2022) 12–17, https://doi.org/10.1007/s12262-021-02962-4.
[118] K. Rosenbusch, Technology intervention: rethinking the role of education and faculty in the transformative digital environment, Adv. Dev. Hum. Resour. 22 (2020) 87–101, https://doi.org/10.1177/1523422319886297.
[119] S. Hashim, M.K. Omar, H.A. Jalil, N.M. Sharef, Trends on technologies and artificial intelligence in education for personalized learning: systematic literature review, Int. J. Acad. Res. Progressive Education Dev. 11 (2022) 884–903, https://doi.org/10.6007/ijarped/v11-i1/12230.
[120] O.H.T. Lu, A.Y.Q. Huang, J.C. Huang, A.J.Q. Lin, H. Ogata, S.J.H. Yang, Applying learning analytics for the early prediction of students' academic performance in blended learning, Educ. Technol. Soc. 21 (2018) 220–232.
[121] S.-C. Tsai, C.-H. Chen, Y.-T. Shiao, J.-S. Ciou, T.-N. Wu, Precision education with statistical learning and deep learning: a case study in Taiwan, Int. J. Educ. Technol. Higher Educ. 17 (2020) 1–13, https://doi.org/10.1186/s41239-020-00186-2.
[122] J. Shen, V.E. Cooley, Critical issues in using data for decision-making, Int. J. Leadersh. Education 11 (2008) 319–329, https://doi.org/10.1080/13603120701721839.
[123] B. Means, C. Padilla, A. DeBarger, M. Bakia, Implementing Data-Informed Decision Making in Schools: Teacher Access, Supports and Use, Technical Report, U.S. Department of Education, Office of Planning, Evaluation and Policy Development, Menlo Park, California, 2009.
[124] J. Murray, Critical issues facing school leaders concerning data informed decision-making, Prof. Educator 38 (2014) EJ1038162, https://eric.ed.gov/?id=EJ1038162.
[125] A.F. Wise, Learning analytics: using data-informed decision-making to improve teaching and learning, in: O.O. Adesope, A. Rud (Eds.), Contemporary Technologies in Education, Palgrave Macmillan, Cham, Switzerland, 2019, pp. 119–143.
[126] C. Thille, D. Zimmaro, Incorporating learning analytics in the classroom, New. Dir. High. Education? 2017 (2017) 19–31, https://doi.org/10.1002/he.20240.
[127] A. Mavroudi, S. Papadakis, A case study on how Greek teachers make use of big data analytics in K-12 education, in: E. Popescu, T. Hao, T.-C. Hsu, H. Xie, M. Temperini, W. Chen (Eds.), Emerging Technologies for Education, in: Lecture Notes in Computer Science, vol. 11984, Springer International Publishing, Cham, Switzerland, 2020, pp. 3–9.
[128] T. Agasisti, A.J. Bowers, Data analytics and decision making in education: towards the educational data scientist as a key actor in schools and higher education institutions, in: G. Johnes, J. Johnes, T. Agasisti, L. López-Torres (Eds.), Handbook of Contemporary Education Economics, Edward Elgar Publishing, Cheltenham, United Kingdom, 2017, pp. 184–210.
[129] D.-K. Mah, Learning analytics and digital badges: potential impact on student retention in higher education, Technol. Knowl. Learn. 21 (2016) 285–305, https://doi.org/10.1007/s10758-016-9286-8.
[130] E.L. Holcomb, Getting Excited About Data: Combining People, Passion, and Proof to Maximize Student Achievement, 2nd ed., Corwin Press, Thousand Oaks, California, 2004.
[131] A.E. Henderson, K. Powers, Developing a data culture, in: K. Powers, A.E. Henderson (Eds.), Cultivating a Data Culture in Higher Education, Routledge, New York, NY, 2018, pp. 3–11.
[132] M.K. Lai, K. Schildkamp, Data-based decision making: an overview, in: K. Schildkamp, M.K. Lai, L. Earl (Eds.), Data-Based Decision Making in Education, vol. 17, Springer Netherlands, Dordrecht, Netherlands, 2013, pp. 9–21.
[133] N. Kingston, B. Nash, Formative assessment: a meta-analysis and a call for research, Educ. Meas., Issues Pract. 30 (2011) 28–37, https://doi.org/10.1111/j.1745-3992.2011.00220.x.
[134] E.B. Mandinach, A perfect time for data use: using data-driven decision making to inform practice, Educational Psychol. 47 (2012) 71–85, https://doi.org/10.1080/00461520.2012.667064.
[135] E.B. Mandinach, E.S. Gummer, R.D. Muller, The Complexities of Integrating Data-Driven Decision Making into Professional Preparation in Schools of Education: It's Harder than You Think, Technical Report, CNA Education, Education Northwest, and WestEd, Washington, DC, 2011, https://educationnorthwest.org/sites/default/files/gummer-mandinach-full-report.pdf.
[136] E.B. Mandinach, E.S. Gummer, Defining data literacy: a report on a convening of experts, J. Educational Res. Policy Stud. 13 (2013) 6–28.
[137] E.B. Mandinach, E.S. Gummer, What does it mean for teachers to be data literate: laying out the skills, knowledge, and dispositions, Teach. Teach. Educ. 60 (2016) 366–376, https://doi.org/10.1016/j.tate.2016.07.011.
[138] K. Schildkamp, W. Kuiper, Data-informed curriculum reform: which data, what purposes, and promoting and hindering factors, Teach. Teach. Educ. 26 (2010) 482–496, https://doi.org/10.1016/j.tate.2009.06.007.
[139] L. Earl, N. Torrance, Embedding accountability and improvement into large-scale assessment: what difference does it make?, Peabody J. Educ. 75 (2000) 114–141, https://doi.org/10.1207/s15327930pje7504_6.
[140] J.A. Marsh, J.F. Pane, L.S. Hamilton, Making Sense of Data-Driven Decision Making in Education: Evidence from Recent RAND Research, Occasional Paper, RAND Education, Santa Monica, CA, 2006.
[141] G.S. Ikemoto, J.A. Marsh, Cutting through the "data-driven" mantra: different conceptions of data-driven decision making, Teach. Coll. Rec. Voice Scholarsh. Education 109 (2007) 105–131, https://doi.org/10.1177/016146810710901310.
[142] A.S. Palinscar, A.L. Brown, Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities, Cogn. Instr. 1 (1984) 117–175, https://doi.org/10.1207/s1532690xci0102_1.
[143] J. van Swet, P. Ponte, Reciprocal learning by experienced teachers and their educators on a master's degree programme in the Netherlands, J. In-Service Education 33 (2007) 67–90, https://doi.org/10.1080/13674580601157711.
[144] P.J. Smith, Technology student learning preferences and the design of flexible learning programs, Instr. Sci. 29 (2001) 237–254, https://doi.org/10.1023/A:1017540131602.
[145] S.D. Teasley, F. Fischer, A. Weinberger, K. Stegmann, P. Dillenbourg, M. Kapur, M. Chi, Cognitive convergence in collaborative learning, in: International Perspectives in the Learning Sciences: Cre8ing a Learning World, in: Proceedings of the Eighth International Conference for the Learning Sciences – ICLS 2008, vol. 3 of ICLS'08, International Society of the Learning Sciences, Inc., Utrecht, the Netherlands, 2008, pp. 360–367, https://dl.acm.org/doi/10.5555/1599936.1600039.

[146] A. Thurston, M. Cockerill, T.-H. Chiang, Assessing the differential effects of peer tutoring for tutors and tutees, Educ. Sci. 11 (2021) 97, https://doi.org/10.3390/educsci11030097.

[147] J. Hollan, E. Hutchins, D. Kirsh, Distributed cognition: toward a new foundation for human-computer interaction research, ACM Trans. Comput.-Hum. Interact. 7 (2000) 174–196, https://doi.org/10.1145/353485.353487.