25 Years of Digital Health Education - Looking Back and Looking Forward

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Abstract

Background: The last 25 years have seen enormous progression in digital technologies across the whole of the health service, including in medical education. For some, digital medical education may seem to have been a brief aberration imposed by the COVID-19 pandemic. However, the rapid evolution and utilisation of online and digital techniques have been significantly transforming this field since the beginning of the new millennium. These continue to rapidly progress even since the resolution of the pandemic.

Objective: This review will aim to outline the striking developments that have taken place in digital health education over this time frame around the world. The learners covered will include medical students, doctors in training or continuous professional development, nurses, paramedics, and also patients.

Methods: Literature reviews were carried out to support this review using PubMed, Web of Science core collection, Google Scholar, Embase, and Scopus

Results: Evidence of the significant steps in the development of digital medical education in the past 25 years is presented and analysed in terms of application, impact and implications for the future.

Conclusions: Major changes and developments in digital health education have occurred since the start of the new millennium. Whilst many of these changes are currently being widely utilised in education, others, such as Augmented Reality, Virtual Reality, and Artificial Intelligence, provide great potential for the near future. Clinical Trial: Not applicable

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Original Manuscript

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Key words:

Digital Health, Digital Health Education, Health Education, Medical Education

e-learning, Telemedicine, Distance Learning, Online Learning

Introduction

The time period of 25 years is an interesting unit of time over which to view changes in medicine or medical education, as it can cover a very significant portion of an individual health worker's career. A medical student starting their course in the year 2000 may well be an experienced consultant or GP by now. What purpose does looking back over such a time frame have for us now? Research is typically forward-looking. However, knowledge acquisition is not an inexorable upward curve of progress. Knowledge can be lost unless we look back for it. In 1901, a strange device-the Antikythera mechanism-was retrieved from an ancient sunken Roman shipwreck just off the Greek island of Antikythera [1]. This was an incredibly complicated, geared analogue computer capable of predicting planetary movements and eclipses. It was over 2,000 years old with no known precursor, and nothing near its complexity would be produced for over a thousand years. The invention and its secrets were lost to history in the shipwreck. We may think in our modern era that such things can no longer happen. However, entering the search term 'Digital Health Education' on Google Scholar since 2023 results in over 1,000 articles. Thus, new discoveries run the risk of being submerged under a sea of data, justifying reviews such as this one.

Since the year 2000, there have been numerous advances in digital technology that have allowed advances in health education. These have included major developments in the World Wide Web (The Web), including the evolution to Web 2.0 and currently into Web 3.0. In addition, new approaches to education, such as Massive Open Online Courses (MOOCs), have emerged in this time period. External factors have had a significant impact too. Whilst the COVID-19 pandemic had a profound global impact, the resulting restrictions of face-to-face activities in many countries greatly accelerated the use-and acceptance of-digital technologies in health education. The effectiveness of digital health education broadly seems to have equivalence to traditional face-to-face approaches [2]. Allied with this, the enormous and expanding economic importance of the e-learning market is apparent. The global e-learning market has been estimated at $6.6 billion (US Dollars) in a report by the International Data Corporation in 2002 and has been estimated to have grown to more than thirty times that value since then [3,4].

Methods

In this review, we will consider technological and educational factors that have developed in digital health education over the last 25 years using literature searches. The scope will include health learners such as medical students, trainee doctors and doctors undergoing continuing professional development (CPD). It will also reference the medical education of nurses and paramedical staff, and briefly touch upon digital health education for patients too. The review will not specifically focus on digital pedagogies which have been covered elsewhere [5]. Literature reviews were conducted to support this review using PubMed, Web of Science Core Collection, Scopus, Google Scholar, and Embase. The first three offer a long search string length, whilst Embase has recently been shown to be associated with a high number of unique references in reviews. The biomedical/health science emphasis of PubMed and Embase is balanced by the broader scientific coverage of Web of Science, Scopus, and Google Scholar [6,7].

Terminology and background to digital education

Before focussing on digital health education, it is instructive to briefly consider the background underpinning it. The terms ‘distance learning’, ‘online learning’, ‘e-learning’, ‘telemedicine’, and ‘digital learning’ have often been used interchangeably, but there are important differences, especially when considering their origins and development. In each case, the terms were coined many years after the process they described had been initiated. The concept of telemedicine remains consistent with its etymology – ‘tēle’ being the Greek word for distance [8], and medicine is derived from the Latin words ‘medicus’, which refers to a doctor or physician, and ‘medicina’, which refers to the practice of healing [9]. Thus, telemedicine is more typically associated with medical practice rather than teaching, although it can used for both. E-learning may be carried out at a distance or in person with a teacher and does not always require connection to the internet. Online learning by contrast implies a working internet connection. Digital learning implies the use of digital encoding of signals, and this largely applies to computer-based technologies, at least until digital televisions became popular around the year 2000. This review will broadly encompass digital health to include online learning, e-learning, and will also include the concept of distance learning. This review will also utilise studies involving ‘blended’ (also known as ‘hybrid’) delivery, where health education is given as a mix of digital (typically distance) learning and traditional face-to-face teaching.

Looking back over the last few decades, we can see that these, and other related terms, continue to be in a state of flux regarding the popularity of use. For example, in Figure 1, the inflexion point of popularity in the term ‘telemedicine’ in the late 1990s occurs at the same time that the term ‘e-learning’ first appears, suggesting this later term may have evolved in part as a simple contraction of the former one. Digital health education is typically used in the context of distance learning, and so it is particularly important to consider this delivery approach first.

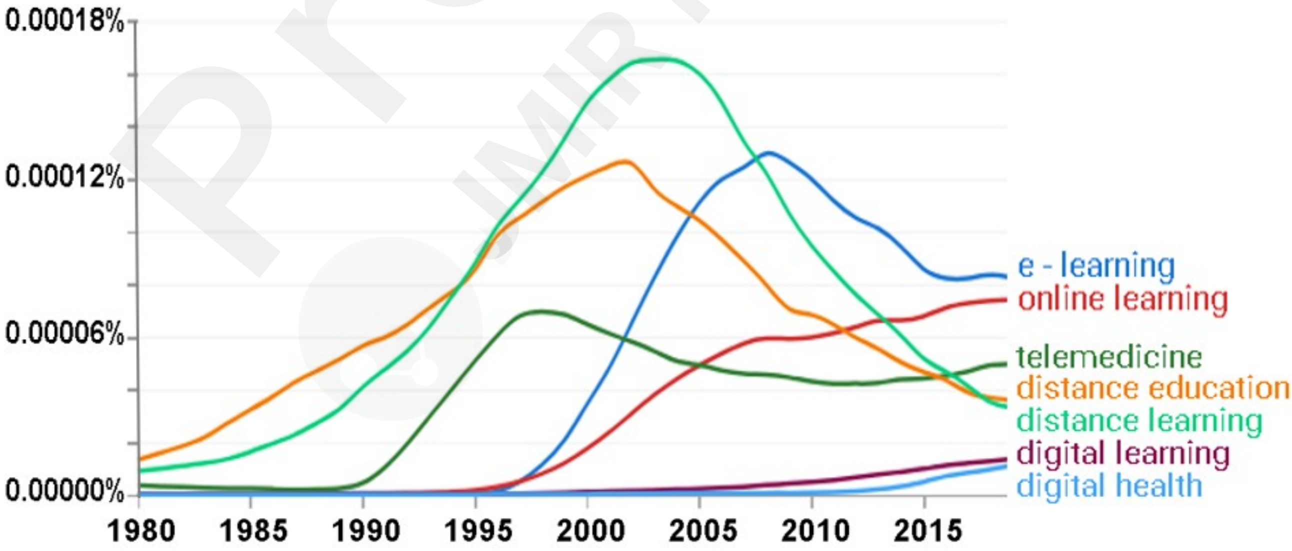

Figure 1: Frequency of usage of phrases related to e-learning by year. Google Ngram illustration showing the frequency of usage by year as a percentage of appearance in the extensive corpus of scanned Google books [10]

From Distance Learning to Digital Learning

Distance learning, where the educator and learner are significantly separated in space, was the first of these techniques to be used. The question of who was the first to use distance learning is debated, with St Paul in the 1st century AD being one candidate, whilst another more typically referenced was Caleb Philipps, who advertised his shorthand lessons by post in 1728 [11,12]. It would be over a century later before Pitman added the important element of feedback in England with the advent of the penny postage system [13]. Major universities provided degrees through distance learning by the end of the nineteenth century. In the early twentieth century, the development of radio and the emergence of television allowed for new opportunities for distance learning. The Programmed Logic for Automated Teaching Operations (PLATO), was the first computer-mediated learning environment, and thus the first medium used for digital learning [14]. PLATO was developed as a working model in 1960 with a distance learning (over 25 miles) application demonstrated using phone connections by the next year [14]. Learners at the University of Illinois using PLATO were able to not only create, but also edit digital images, helped in part by the use of plasma screens with touch-sensitive screens in 1966 [14]. One of the very first simulations used for teaching was possibly the first example of digital health education in 1963; a case study of an acute myocardial infarct was presented to students with various treatment options, with PLATO then providing feedback [14]. The students taught via PLATO outperformed those taught with conventional face-to-face methods, and by the mid-sixties, the first fully online university course was developed.

In 1969 the Open University was established in the UK, utilising radio, television and the postal service. By 1984 it would have 60,000 undergraduate students studying at home [15]. Whilst massive in scale as a distance learning institute, by the early 1980s, the Open University could also be genuinely described as providing digital learning, as the use of the CYCLOPS computer system allowed interaction between tutors and students via a telephone-conferencing network [15,16]. The resulting diagrams could then not only be displayed on a television monitor, but also edited with light pens.

The year 1969 was fundamental in the evolution of digital learning as it saw the U.S. Advanced Research Projects Agency Network (ARPANET) link different computers together using a packet-switched computer network [17], although the absolute precedence of ARPANET here has been disputed [18]. This would develop into connections between networks (‘internets’) and then to ‘the’ internet in the early 1980s. Subsequent global reach was achieved through The Web from the early

1990s onwards, with web servers and webpages rapidly increasing in number. At the start of our designated review time period, The Web (retrospectively termed Web 1.0) had a fixed, search and read-only capability. In 2004, a major advance was the Web 2.0 version, which now allowed for read and write capabilities, making it much more interactive [19]. This would be a key progression from a digital health education perspective, improving dynamic communication between learners, their online courses, and their tutors. From 2008, the launch of MOOCs built on the improvements seen in Web 2.0 [20]. MOOCs underwent rapid expansion from 2012 onwards, with both Udacity and EdX (a Harvard University MIT collaboration) founded that year [21]. The gradual introduction of Web 3.0 (also termed Web3) at this present time has a less centralised structure and allows greater use of more complex semantics by users without having to break these down into simpler components. Web 3.0 also offers a more flexible schema of data storage and interactions between data [19]. Whilst Web 1.0 was considered ‘read-only’ and Web 2.0 is ‘read-write’, Web 3.0 has been described as ‘read-write-own’, allowing some degree of digital ownership [21]. The metaverse, in which virtual worlds can be developed where digital avatars can interact, has been closely associated with the rise of Web 3.0 [22]. The possibilities of multiple users interacting directly is of great potential for digital education involving classroom interactions online. The decentralised concept of Web 3.0 provides the potential for greater dissemination of education, whilst also posing challenges for education providers in terms of possible loss of some control over content. At the same time, individual educators and educator companies now have increasing opportunities to interact with learners directly using the blockchain features of Web 3.0 to monetise the services they provide, potentially bypassing traditional education institutions [21].

Learning Management Systems and Digital Health Courses

Learning management systems (LMS), sometimes referred to as e-learning platforms, are digital spaces where learners can access educational content, courses, and resources online. Like many other teaching fields, medical education has seen rapid growth in the use of these digital platforms, adding complementary mediums for learning alongside traditional didactic methods [23]. These platforms may offer a variety of features, such as video lectures, interactive quizzes, discussion forums, and assessments. Frequently used examples of LMS include Canvas, Blackboard and Moodle, the latter being an example of an open-source e-learning platform frequently used in digital health education [24]. Teaching Institutions can use such e-learning platforms to create, manage, and deliver online courses. Educators can engage with students through forums, messaging, and collaborative activities while tracking progress through analytics. Videoconferencing using LMS can allow live synchronous interactions across continents, allowing real-time health student feedback on questions, teaching, and even on the course itself [25]. LMS use can allow whole courses to be structured and developed, giving the potential for large-scale open access health courses too through MOOCs [20].

A systematic review commissioned by the World Health Organisation found that e-learning in medical education using such e-learning platforms was equivalent in terms of skill and knowledge acquisition compared to traditional face-to-face courses [26]. These digital platforms also offer health students the ability to customise and adapt their educational experience by pursuing extra content in subjects of interest or by engaging with content that better caters towards their personal learning style [27]. Additionally, e-learning platforms provide flexibility for medical students by distributing asynchronous learning materials such as case studies, pre-recorded lectures and question banks, accommodating varied lifestyles and schedules [28]. These characteristics of digital platforms may improve satisfaction and engagement with medical education when used alongside traditional teaching methods, while also helping to build skills in autonomous regulation and independence when trying to meet learning goals [29]. It is also easier to update and restructure content on digital learning platforms, keeping medical educational materials more current than traditional syllabi and textbooks, which cannot be readily reviewed as regularly.

The interactive dimension of many health courses adds a particular emphasis on enhancing interactions with students despite the online delivery. The evolution of e-learning platforms has played a significant role in the practice of blended learning, which has been adopted into the curriculum of many institutions for medical education [30]. Blended learning has been demonstrated to yield significantly better knowledge outcomes in health education compared to traditional techniques [31]. E-learning may be more effective in the acquisition of factual knowledge, such as basic scientific principles or mechanisms, compared to traditional approaches in developing clinical skills, physical examinations and communication abilities [32]. With traditional face-to-face interactions, simulation teaching, either with manikins or standardised patients (typically actors), can be used in teaching such medical scenarios. More recently however, it has been shown that the use of LMS learning platforms can also be used to create effective online simulation training in health education [33].

Digital question banks on LMS and interactive e-learning content have become some of the most popular revision methods for medical students, with studies demonstrating these may be used by up to 92% of students [34]. Many of these digital learning platforms employ the concept of gamification by using instantaneous feedback from quizzes and the idea of ‘streaks’, which encourage students to keep daily engagement with the platform [35]. These features are thought to increase student motivation and make it easier to track and visualise progress. Digital platforms may also use competitive aspects like leaderboards, badges, points and challenges, allowing medical students to compare their progress with each other, and may make learning more enjoyable [36]. These e-learning materials have also demonstrated efficacy in the continued education of health professionals, without any evidence that these methods of learning affect professional behaviours or patient outcomes [37]. A scoping review evaluating digital health education for medical students between 2000 and 2019 found that such courses varied in terms of delivery and assessment, were mainly delivered as electives, and often lacked robust evaluation [38].

From a wider perspective, digital education platforms may help reduce geographic and financial barriers to medical education, by allowing educators to share knowledge across borders. There is evidence that e-learning platforms can improve educational opportunities for medical students in resource-constrained lower-income countries [39], however inequalities in internet connectivity, technology, and language barriers, could potentially worsen the disparities in health knowledge. It is important that e-learning content aligns with medical curricula and is standardised. This can be achieved by developing quality assurance and guidelines for these platforms, through collaborations with accrediting institutional bodies [40].

Evidence also suggests that medical students find e-learning platforms to be effective in improving understanding and are associated with high satisfaction scores [41]. Health student satisfaction overall with LMS use in medical education appears to be high - with over 94% of medical and nursing students recently showing satisfaction with the LMS used in China [41]. It is likely therefore, that these digital platforms will continue to play an important role in the educational toolkit of the modern-day health students.

Telemedicine and digital health education

Telemedicine allows for the transfer of medical services from health professionals where distance may have otherwise been a limiting factor, and it has been used across specialties [42]. It can also play an important role in digital health education. The main methods for the delivery of telehealth training in digital health education range from traditional lectures to simulation-based education [43] and cover a broad range of skills. In training for telesurgery, for example, medical students can observe procedures, and enter associated case-based discussions. Training for health professionals often requires more active manipulation of tools with live feedback from remote educators, a form of interactive and immersive teaching method that is generally well tolerated [44]. In addition to ensuring that users are familiar with how to use telehealth to deliver effective medical care [45], they should be trained on how best to maintain patient confidentiality and privacy in telemedicine [46,42}. From the late 1990s, training in telemedicine was in its developmental stages [47,48], and there was limited utilisation in training at the undergraduate and postgraduate level [48]. Where training was available, programs were aimed towards practising medical professionals, and often specific to a form of telemedicine [48,46]. In addition to direct training, telemedicine can be used to provide telementoring of learners [49]. In recent years medical training curricula have shifted to include training and education in telemedicine [42], which was not previously the case [48]. By 2019, just before the COVID-19 pandemic, 25% of American medical schools included telemedicine in their curricula [45]. Goals for training include improving decision-making, and coordination [50] to facilitate the delivery of holistic, comprehensive healthcare through telemedicine. However, despite the numerous benefits that telehealth training can bring, telemedicine cannot fully replicate in-person rapport building, body language cues [42] and clinical skills essential for medical students, despite the efforts of existing non-verbal communication training platforms [51]. Thus, while it has been suggested that the greatest benefits are to be gained when training is commenced in earlier stages of medical education [52], a combination with traditional teaching may provide the best balance. Challenges looking forward include the expansion of telemedicine more equitably, particularly targeting lower-income countries and rural areas even amongst high-income countries [53,42].

Mobile health and digital health education

The last 25 years have seen a surge in the use of mobile technology worldwide [54,55,56]. The increased use of mobile health applications (apps) [57], particularly within digital health education, partially reflects the ease of access they can provide. Mobile health (mHealth) defines the use of mobile devices for medical practices [58], for example through programs – also known as mHealth apps [56]. Such apps can support both healthcare and digital health education [59,60]. Examples of mHealth use in digital medical education include online textbooks, podcasts, medical calculators and online lectures [59,58,55], as well as virtual anatomical models used to visualise structures in 3D and medical scans [55]. Simulation apps such as Touch Surgery [61] can be used to effectively learn, consolidate and practice surgical manoeuvres, and clinical skills such as cardiopulmonary resuscitation [62,63]. Additionally, mHealth applications can facilitate collaborative learning, continuing medical education and clinical decision-making [55,59,60], In addition to providing education for health students and professionals, the ease of access of mHealth apps allows them to be used for health education of patients too [55]. This educational content can range from teaching patients rehabilitation for chronic obstructive pulmonary disease [64,65] to providing general explanations for their symptoms.

Both within and outside lecture halls and clinics, mobile devices have proven to be a valuable resource for accessing educational content where distance, resources or financial situations may have previously been a limiting factor [61,55,60,66]. While some apps have paid components [62,55], the low costs of many apps lessen the potential of financial barriers for many learners [59,55]. In order to maximise the educational benefit and maintain user interest, mHealth apps, like LMS platforms, have implemented strategies such as interactive quizzes, instant feedback and gamification [67].

As with many digital health resources, concerns for privacy and confidentiality should be addressed [59]. This can in part be mitigated through regular updates of antivirus software, however, the risk of a mobile device being stolen or lost remains. Another challenge may be that the convenience and subsequent reliance on mHealth educational resources could compromise the standard and depth of internal thought that is required in medical practice [59]. Furthermore, physical limitations such as screen size [55], and obstructing the device screen during interactive elements [62] can restrict the ways mHealth apps can be used for medical education.

Finally, whilst mHealth apps may be accessible [58,66], a concern amongst users regards the accuracy of results [59]. For example, it was noted in 2012 that over 44% of apps providing information on cancer gave data that was not scientifically validated [54]. There is not yet a standardised protocol for establishing the quality of mHealth applications [67]. The increased utilisation of mHealth apps for medical education in recent years [68] reflects the call for such expansion in the early 2010s [55]. Looking to the future, the potential for mHealth apps to further transform digital health education appears significant, potentially with increasing use of artificial intelligence (AI) [67]. Further expansion of the reach of mHealth education apps geographically will be an important goal once concerns about equitable access to technology have been addressed. One important aspect in relation to this is the need for apps to be available on multiple operating systems [55,67].

Big data and analytics in Digital Health Education

Through ever-increasing interactions with digital technologies, users generate large amounts of data. Big Data Analytics (BDA) describes the process of collecting and interpreting these large datasets in order to gain meaningful information. As the scale of the data grows too large for traditional analytical techniques, the emergence and optimisation of machine learning and other AI models have become increasingly important in allowing subsequent processing. BDA use is widespread across industries and has been associated with reduced costs, improved productivity and impact on decision making [69]. In the last decade, developments have been made in the use of BDA in healthcare, supporting improvements in patient monitoring, data-driven diagnosis, management of hospital resources to improve service quality, and evidence-based decision making at both a public health policy level and local level [70]. However, applications of BDA for digital health education have only begun to accelerate in more recent years [71]. BDA holds great potential to enhance learning, although a recent systematic review showed that analytics were most frequently used to simply capture the number of connections made by students to the learning material, while areas such as feedback and at-risk intervention were yet to be fully employed [72].

A key quality of BDA lies in its ability to support decisions. Changes to curricula, course structures and admissions policy can be visualised by their impacts on performance data [73], allowing programme directors to swiftly notice patterns and respond to them. Additionally, accumulating performance data could help generate benchmarks for programmes as an additional metric for ensuring quality standards. On an individual level, BDA can help to identify or predict students and trainees who are struggling or at risk of underachieving, allowing extra intervention to be provided for them [74]. However, there has been some debate as to the psychological consequences of using predictive analytics in this way and whether it may potentially exacerbate a student's struggles by prematurely labelling them as falling below a certain metric [75].

Digital health education platforms and institutions may also use BDA as a form of feedback by using data patterns on engagement and machine learning instead of manual questionnaires, helping to save time and potentially producing more valuable insights into where improvements need to be made in health education [76]. For example, data on whether medical students engaged with digital content (such as clicking hyperlinks or magnifying images on course webpages), demonstrated value in predicting which students would perform better at examination [77]. With focused use, this could also help to elucidate and optimise methods of learning useful in understanding specific medical content and could aid in personalising the education process. Data collected about learners should be fed back to them, closing the loop and allowing them a greater understanding of how it is being used and how this will benefit them [78] A way of doing this is by creating personalised dashboards for students which systematically deliver and help visualise performance data [79].

Performance data on clinical skills such as catheter insertion, can create a baseline to judge when a student is ready to perform such skills on a real patient, while also providing the student with reassurance and confidence when they are ready [73]. An ambitious endeavour of BDA can arise from the combination of data on clinical information in hospitals with data from medical education, in order to gain an insight into how different medical curricula and educational models impact patient outcomes [73]. However, it may be difficult to interpret these data-generated patterns, as many other factors can affect clinical outcomes, including team decisions, local practices and technological disparities, making it hard to attribute results to individual educational programs [80]. Other challenges associated with BDA still require consideration. Emerging patterns could be misinterpreted, as data may simply be correlated and not causally linked [73]. Additionally, as with other large datasets, there is the potential trap of finding examples of significant patterns that may not necessarily be meaningful [81]. Traces of a learner's digital data, reflecting their behaviours online, may potentially be gathered as part of big data when using digital health technologies in education [82]. It is still unclear what the exact limits on the use of such data would be, yet it is an important area to be cognisant of, given the increased use of such technologies in digital health education [83].

The Metaverse, Augmented Reality and Virtual Reality in Digital Health Education

The metaverse is a three-dimensional virtual world in which users can interact both with other users and with digital objects [21]. Whilst not a new concept, more recent rapid development of associated tools such as blockchain and non-fungible tokens, as well as the close association of the metaverse with the evolving Web 3.0, have created considerable potential in digital environments-including digital health education. As the metaverse is built around extended reality technology aimed at making an immersive experience for users, the more focused terms of Augmented reality (AR) and Virtual Reality (VR) are important to consider [21]. AR involves a digital overlay on top of the real world, whilst VR involves fully immersing into the digital sphere [84]. Both AR and VR can be realised via head-mounted devices [85] or digital glasses [86]. AR has shown significant value in training techniques across numerous specialties and is seen frequently in surgery [87]. For example, Google Glass demonstrated positive outcomes in medical students and urological surgeons at various stages of training [86].This training allowed for a sense of reality during the training environment, which was particularly favoured by the younger participants. AR has also shown benefits for students studying anatomy, with AR textbooks better assisting student learning compared to standard textbooks [87]. Students taught with AR were also noted to have better performance in long-term spatial anatomy knowledge compared to the students who were taught traditionally [87].

In terms of the efficiency of VR, a randomised controlled trial carried out with Japanese nursing students noted no significant differences between VR and traditional teaching methods in both groups, in terms of skills, knowledge, or confidence [88]. Strikingly, the only statistically significant finding was a higher satisfaction rate in students who were taught traditionally, likely due to the sickness associated with VR adjustment. The study had a small sample size and was only tested on third-year students. Similar results were seen in a study on undergraduate paramedic students, with no significance between the results of those who had lecture-based teaching and those who had VR-based teachings [89]. However, a systematic review evaluating immersive VR use in nursing education [90], highlighted that there is generally a positive response to VR-assisted learning amongst nursing students. This included reduced anxiety in those performing skills in real life with prior VR practice, due to 360-degree simulations that resembled real life more closely than simulation situations with manikins or lectures. A systematic review [91] found similar results, with the efficiency of VR typically not being statistically different to traditional teaching methods. However, it was also noted that the majority of trials using VR used it as an intervention only once, and there was a lack of data showing how VR faired to traditional teachings across multiple sessions. VR simulators have shown significance compared to controls in providing greater self-confidence for surgical residents in dentistry [92]. It was also identified that residents who used VR navigation software had higher accuracy in marking their first implantation sites during the surgical stage of dental implantation [92]. A recent meta-analysis [93] showed that teaching health professionals with VR interventions that are mostly interactive resulted in a considerable improvement in skillset and to a lesser extent, improvements in knowledge compared to traditional methods. Both AR and VR have shown promise in undergraduate students as active learning methods for teaching anatomy. Combining these methods into extended reality teaching was perceived by health students as more useful than traditional methods [94].

There are some device-related downsides to both AR and VR as they are primarily dependent on the associated headsets or digital glasses. For example, users who already wear glasses report discomfort when wearing such devices over the top of them [86]. Device use may also be associated with nausea, motion sickness (sometimes termed 'cybersickness') [84], technical difficulties and stress, and it is unclear whether such symptoms resolve as a participant gets used to the experience over time or whether they are long-lasting symptoms [84,85]. The devices also require regular charging which can be inconvenient when needed for long periods of time. Furthermore, there are concerns about accessibility to such education in low- and middle-income countries, despite having populations that might particularly benefit from AR and VR-based education due to unequal distribution of health professionals. This inequality can be seen in many countries, including higher-income ones, with internal disparity between urban and rural areas [85].

There are some scenarios where student confidence in AR or VR education techniques may be misplaced, as a systematic review [84] suggested a challenge of remote VR education may be a lack of direct supervision and evaluation of student performance. Additionally, there may be limited technical support for those who may find it difficult to manage the complexity of VR independently. Increasing student engagement with AR or VR teaching through utilising games, simulations and interactive scenarios has shown promise [95]. Gamifying digital learning materials may also increase social connectivity, helping to combat the risk of social isolation in remote learning.

As technology and material become more readily available, the overall cost of AR and VR should decrease, improving accessibility in low- and middle-income countries. Currently, VR, metaverse and AR are not widely available in medical or health curricula, and there is a lack of standardisation or set guidelines. Likewise, there is a need to develop clear guidance for potential users of AR and VR to determine if any preexisting health conditions might need additional support or cautions before using these devices [84].

COVID-19 and Impact on Digital Health Education

The COVID-19 pandemic in early 2020 impacted nearly 1.6 billion learners - 94% of all students worldwide at the time - with enforced social distancing necessitating rapid and significant changes in education, particularly with a pivot from face-to-face to distance digital delivery [96]. For many educators, who might previously only have been used to teaching face-to-face, the very rapid change required to convert to distance learning with digital delivery created tremendous challenges

[97]. The rapid upskilling of such individuals in fundamental digital skills, such as the use of videoconferencing, was vital across many courses globally, including in health education. For most educators, the immediate practicalities of rapidly upskilling educators and changing delivery to digital format had to take precedence over exact pedagogies [96]. Pre-existing deliverers of digital medical education were in a position to help their peers to adapt. There were significant challenges faced by students too [98]. For those who had originally applied for fully face-to-face courses, the experience of distance learning may have been very different from what was anticipated. We should not underestimate the very significant added stresses of the time [99]. Where in many countries lockdowns added restrictions of movement to concerns about risk to personal health or the health of loved ones. These multitude of factors make it difficult, even in retrospect, to fully analyse the effectiveness of digital medical health education during the pandemic. However, what does seem certain is that the COVID-19 pandemic was associated with a much wider dissemination of digital health teaching [100].

Much of the early literature published during the time of the pandemic focused on the adaptations used by medical health educators to pivot to the digital environment. Many of these specifically looked at the practical steps that were required, including training on acceptable behaviours expected during these digital meetings, especially using videoconferencing [100]. There appear to be more studies performed in the USA that reported direct use of online discussions with a patient (telemedicine) as part of the digital education delivery to students as compared to the UK and Europe [100]. Whilst videoconferencing theoretically might enhance focus on history taking when direct physical examination was no longer possible, prolonged use of videoconferencing was associated with learner fatigue-in some cases postulated to be related to critical self-analysis of the learner’s own face appearing on the screen during teaching [101].

The enforced change of educational delivery to digital platforms away from classrooms may have risked some social isolation, especially in university student populations where much socialisation occurs within in-person classes [98]. Various techniques have been used during videoconferencing to help improve focus and engagement between students and educators, and between students. Regular chunking of information and use of breakout rooms may have benefited some in these regards. With apparently less forthcoming students, sometimes referred to as ‘lurkers’ [100], these techniques may have been effective. The interactive behaviour of online learners has sometimes been sharply divided into ‘The workers, the lurkers and the shirkers’ [102]. However, the role of more passively ‘lurking’ in the background during videoconferencing calls may in fact be used by the majority of attendees early on as they adjust to the meeting and then can participate more fully [103].

Despite the challenges of the time, student surveys during the pandemic revealed some positive feedback regarding their enforced online medical education [104]. Since the last of the lockdowns in most countries was lifted, beginning in March 2021 in England [105], evidence overall indicates that there has been increased use of digital education methods since pre-pandemic time [100]. For example, in the USA, the total number of students enrolled in degree-granting post-secondary institutions who had at least one of their courses delivered online was over 14 million (75% of the total) at the height of the COVID-19 pandemic in autumn 2020, but was still over 11 million (60% of the total) in autumn 2021, well after nation-wide lockdowns had been lifted [106]. This was still substantially above the pre-pandemic 2019 level when 42% of postbaccalaureate (postgraduate) students were enrolled in at least one distance education course [106].

Many learning institutes had not only upskilled educators, but also invested in the technology to permit digital learning [107]. The usage of digital media in health education has not returned to pre-COVID-19 levels. In addition, the sudden enforced changes in education during COVID-19 may have made change in previously accepted higher education structure easier to gain ground. For example, we are seeing a rapid rise since the pandemic in alternative courses to formal higher education degrees such as microcredentials and digital badges, with which digital health education can be used to offer greater flexibility to learners than with traditional degree courses - even compared to those with a modular structure [108].

Ethics and Cybersecurity in Digital Health Education

The ethical and legal considerations of digital health education have not been explored in extensive depth in the currently available published literature, but some extrapolation is possible from work looking primarily at digital health. A recent review found that a digital divide between users with different characteristics, especially those with different ethnicities or income status, contributed significantly to social health inequalities [109]. Likewise, digital health education may be a disproportionately less available option in racial or ethnic minorities, older adults, and in those with limited health literacy [110]. This raises concerns over the fairness of accessibility of educational resources across all demographics. The Open Access model, used successfully in many medical journals, might provide a model to follow in trying to develop greater equality of digital health education, potentially building on some of the challenges which still exist in some areas of open access [111].

Health organisations do not always have the level of cybersecurity needed to prevent unwarranted access to personal patient information [112]. Thus, it could be inferred that educational content created from patient information or sensitive data may not be secure. This should be borne in mind when consenting patients for the use of such material (such as medical photography) in education. Safeguards should be put in place to restrict the inappropriate distribution of such content to unintended personnel through means like social media [113]. This is especially the case in digital education, where images and videos might be stored for long-term use, including downloading, manipulation and uploading [114]. The use of encryption software may aid in securing data with sensitive information, with multiple layers of encryption providing stronger protection [115]. This may help overcome some ethical concerns over data storage, as not only text, but also some photos and videos can be anonymised. General Data Protection Regulation (GDPR) compliance is important in digital health as a whole, with aspects such as obtaining informed consent, and ensuring data minimisation and anonymisation carried out where possible [116]. Secure password protecting of accounts and software or creating personalised links for individuals may help ensure that data is only accessed by people with given log-ins, helping to regulate those who can access educational software that includes patient images or data. As well as ensuring data protection protocols are followed, it is also fundamental that the significance and impact of data protection is taught to health students who are increasingly accessing health and education digitally. It is, however, currently unclear how widely digital health competencies have been achieved amongst health workers in dealing with aspects such as electronic health records [117,118].

One possible risk of increasing use of digital health education is that it might contribute to digital addiction, potentially affecting 25% of the general population, especially in instances of AR and VR being integrated into health education through game-like applications [119]. There are concerns that technology overuse due to the introduction of digital health education might exacerbate social isolation and reduce opportunities for health students to benefit from positive role modelling of professional behaviours, such as empathy and communication skills [98].

Artificial Intelligence (AI) in Digital Health Education

Although the term Artificial Intelligence (later abbreviated as AI) was first coined in 1955 [120], it is in the last decade that dramatic developments in this field have led to both great potential and great challenges for digital health education. AI has been used in areas as diverse as medical practice management, patient monitoring, diagnostics and device integration [121]. In the field of BDA, the AI related technique of natural language processing (NLP) helps computers interpret and communicate responses in human language [122]. The specialty of radiological diagnostics in particular has seen a particularly striking impact, with AI tools having been shown to perform better than experienced radiologists in some tasks [123]. Despite this, the use of AI in digital health education has to date lagged someway behind its use in medical practice. Large language models such as the Chat Generative Pre-trained Transformer (ChatGPT) have becomes very widely used in the last two years across many disciplines. Despite a number of potential challenges, they can quickly offer a very brief summary of many long established facts in medicine [124]. As such they can be used to help in part when preparing medical education. Because of plausible errors and data set time limitations, current use of such language studies may be less effective for students than for experienced educators who could more easily spot errors. Examples of ways in which medical educators might use tools such as ChatGPT have included virtual patient simulation, quizzes for medical students, summarising research articles and generating brief curricula for digital health learners [124]. However, the rapid production by large language models of material which can be very relevant, gives rise to concerns that some students might use them to help answer examination questions. Last year it was shown that ChatGPT could perform as well as a typical third-year medical student on the United States Medical Licensing Examination (USMLE) Step 1 and Step 2 exams, and further improvements in performance are likely [125]. It is nevertheless possible that students might benefit from the dialogue interaction with ChatGPT to add exploration of concepts when learning about topics by themselves or with peers [125]. It is currently not possible to detect with certainty if work submitted by a student had used AI to answer examination questions, and this is especially a concern with non-invigilated examinations. Whilst tools such as generative textual likelihood ratio (GLTR) can increase detection by humans of work made using large language models, the implications of plagiarism are so great for a student that even 99% accuracy may seem insufficient to confidently declare work to have been made with such AI models [126]. As such, teaching institutions are having to reconsider the assessment environment for students with invigilated face-to-face or distance learning examinations in real time. Alternative approaches such as higher marks for critiquing, use of modern references or interpretation of medical images by students may currently also help, but even these may become less challenging for large language models in the near future [127]. A similar concern in digital health education extends beyond students. A recent paper demonstrated that it was possible using ChatGPT (GPT 3) to deliberately produce a fraudulent paper nearly 2,000 words long with 17 references in just an hour. Whilst there were some errors such as false references, so called ‘hallucinations’ [124] which an expert might detect, this detection rate may decrease in time as Large Language Models continue to improve.

AI text-to image generation of quite atypical images of physical appearance has proved possible with the addition of diffusion models, allowing the potential production of illustration even of rare medical conditions [128]. There has been some work on the use of AI text-to image generation in producing photographic quality medical illustrations. For example, images of arthritis, a potential thyroid mass and hypothyroidism have been produced as entirely novel images not based on traditional photographs of patients [129,130]. The images of the face in particular may offer great promise as an alternative to traditional patient photographs where the very important issues of consent and confidentiality may limit the images available. Such AI text-to image generation can also rapidly produce novel pictures to illustrate case studies for teaching. Many tools are now also widely available to produce new, short videos from AI text-to-video prompts. However, most to date mainly employ speaking avatars (with some degree of apparent lip-synching) on a background of very short traditional stock video clips which are linked together via AI to create a finished video. These certainly have the potential to enliven a short text teaching session. There is also rapidly evolving work on creating genuinely new moving images without the use of stock videos. OpenAI have recently demonstrated some very clear short videos using SORA which may be more widely available later in the year [131].

Some concerns have been raised about AI-generated images, including the limits of copyrighting such images and the lack of clarity about the original dataset of images used to train the Generative Adversarial Networks through which AI image-generating tools are developed. Other potential issues such as accuracy, and potential perpetuation of stereotypes (including skin colour and perceived gender) have been raised [132]. Similar concerns have been raised for text-to-video generation, with the possibility that inaccurately portrayed medical images or deliberately misleading videos (including 'deep fake' images) may be produced [131]. Watermarking of work produced using large language models and text-to-image generation has begun this year, although this may not be impregnable [126]. Despite these considerable cautions, the field of AI text-to image and text-to video generation seems to have great potential for the near future of digital health education, whilst respecting the important challenges that have been mentioned in this field. This marks AI as one of the biggest potential areas of growth in medical education looking to the immediate future.

Conclusion

Digital health education continues to expand rapidly with great hope on many fronts, especially from applications in AR, VR and AI. Several key challenges require ongoing attention, however. These include the need for improved accessibility to relevant technologies and, in some areas, improved internet connectivity. Ethical challenges also exist on a number of fronts, especially surrounding consent, confidentiality and ownership of online material used in digital health education. The time period of the last 25 years has seen extraordinary developments in digital technology. Whilst a boon for many, this relentless progress may leave some learners, and even some educators, feeling insufficiently skilled to fully participate in the evolving digital landscape. Some have been left with feelings of stress or even become fearful that they might not be able to keep pace with the changes [100,99]. In 'The Prince', Machiavelli famously argued that it is better to be feared than loved [133], however, surely the reverse should be true for the continued advances in digital technology. Despite the many concerns about the rapid advances in technologies underlying digital health education today, these changes should be embraced rather than feared, giving us further opportunities to help our learners. We can then look back on the rapid advances that have already been made and look forward to more. At its heart, however, digital health education will always be more than the technology, and rather should enhance ways that we as educators can reach, support, motivate and empower our learners.

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Supplementary Files

Figures

Frequency of usage of phrases related to e-learning by year. Google Ngram illustration showing the frequency of usage by year as a percentage of appearance in the extensive corpus of scanned Google books [10].