Data Science Evolution and Application in Medical Education

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Abstract
Data science application in medical education is rapidly evolving. This article defined data science and its application in various domains of mathematics, statistics, artificial intelligence, computer engineering and medical education. The concepts frequently deployed in artificial intelligence such as deep learning, big data and machine learning were explained. A brief overview of evolution of data science was narrated and breakthrough moments were equally highlighted. Medical education and its peculiarities as well as the various challenges encountered in Nigeria were examined. The value of integration of medical education and technology along with the attendant benefits was highlighted. Appropriate recommendations were made on the need to leverage on data science to improve learning experience and outcomes in medical education.
Keywords: *Evolution, Data science, Artificial intelligence, Medical education, Application*

Introduction

Data science is the study of data with the goal of gaining important business insights. It is a multidisciplinary method for analyzing massive volumes of data that integrates ideas and procedures from the domains of mathematics, statistics, artificial intelligence, and computer engineering. Other academics have defined data science as the discovery of actionable insights buried in an organization's data using a combination of mathematics and statistics, specialized programming, sophisticated analytics, artificial intelligence (AI), and machine learning(Vaswani, 2017). These revelations are then used in strategic planning and decision-making. When considered as abstract ideas (pure mathematics) or as applications to other fields like physics and engineering (applied mathematics), mathematics is the study of numbers, quantity, and space. Mathematics can also be described it as the branch of study that deals with the construction and measurement of shapes in space as well as the qualities, relations, and operations of numbers.

The practice or science of statistics is the wide-scale collection and analysis of numerical data, primarily with the goal of extrapolating representative sample proportions to the population at large. In contrast, artificial intelligence (AI) is the idea and creation of computer systems that are capable of doing activities that would typically require human intellect, such as speech recognition, visual perception, decision-making, and language translation (Nguyen, 2022).

Big data is information that is more diverse, coming at a faster rate and in larger amounts. Big data, especially from new data sources, are larger and more complicated data collections. Artificial intelligence (AI) machine learning teaches computers to learn from experience. Without using a preexisting equation as a model, machine learning algorithms employ computer techniques to "learn" information directly from data (Nguyen, 2022). The artificial intelligence (AI) technique known as deep learning, on the other hand, teaches computers to

interpret data in a manner that is similar to the way the human brain does. Deep learning algorithms can identify intricate patterns in images, text, audio, and other types of data to generate precise analyses and forecasts. Several areas of computer science and electronic engineering are combined in the branch of electrical engineering and computer science known as computer engineering in order to build computer hardware and software (Waldrop, 2019).

The evolution of data science

Over time, both the phrase "data science" and the discipline itself have changed. Due to advancements in data gathering, technology, and the huge output of data globally in recent years, its popularity has significantly increased. The day when data workers had to rely on pricey applications and mainframes is long behind. The emergence of programming languages like Python and methods for gathering, analyzing, and interpreting data helped make data science the well-liked discipline it is today.

Statistics was the foundation of data science. The incorporation of concepts such as machine learning, artificial intelligence, and the internet of things was a part of the evolution of data science. With the influx of fresh data and corporations looking for new methods to enhance profits and make better judgments, data science began to spread to other sectors such as medical, engineering, and others (Dataquest, 2021).

Data science arose from the notion of combining applied statistics with computer science. The new branch of research would make use of contemporary computing's amazing capabilities. Scientists recognized they could not only gather data and solve statistical issues, but they could also utilize that data to address real-world problems and produce fact-based forecasts.

John W. Tukey, an American mathematician, described the data science goal for the first time in 1962. In his now-famous paper "The Future of Data Analysis," he predicted the rise of a new discipline about two decades before the first personal computers were introduced. Tukey was ahead of his time, but he was not alone in his early understanding of what became known as "data science." Peter Naur, a Danish computer engineer, was another early pioneer, and his book Concise Survey of Computer Methods has one of the very earliest definitions of data science: "The science of dealing with data, once they have been established, while the relationship of the data to what they represent is delegated to other fields and sciences." In 1977 , the theories and predictions of "pre" data scientists such as Tukey and Naur became more concrete with the establishment of The International Association for Statistical Computing (IASC), whose mission was "to link traditional statistical methodology, modern computer technology, and domain experts' knowledge in order to convert data into information and knowledge."(Dataquest, 2021).

The 1980s and 1990s saw the formation of the first Knowledge Discovery in Databases (KDD) workshop and the establishment of the International Federation of Classification Societies (IFCS). These two societies were among the first to focus on teaching and training professionals in data science theory and technique (albeit the phrase had not yet been properly established). At this moment, data science began to gain traction among top executives looking to commercialize large data and applied statistics. BusinessWeek released an article in 1994 about the emerging phenomena of "Database Marketing." It represented the

process by which organizations collected and analyzed massive volumes of data in order to learn more about their consumers, competitors, or advertising tactics. The main issue at the time was that these businesses were being inundated with more information than they could properly handle. Massive volumes of data sparked the initial wave of interest in developing specialist data management professions. It seemed that corporations would require a new type of worker to make data work in their advantage (Chen, 2022).

In 1990s and early 2000s, data science had definitely evolved as a recognized and specialized discipline. Several data science academic publications began to circulate, and data science advocates such as Jeff Wu and William S. Cleveland continued to develop and expand on the importance and promise of data science (Radford, 2019).

In 2000s, technology advanced dramatically, allowing practically ubiquitous access to internet connectivity, communication, and data collecting. Big data made its debut in 2005. With internet behemoths like Google and Facebook finding massive quantities of data, new technology capable of processing it became essential. Hadoop rose to the occasion, and Spark and Cassandra followed suit. By the year 2014, the value of data was growing, as did businesses' interest in detecting patterns and making smarter business decisions, demand for data scientists began to rise dramatically in many regions of the world. The year 2015 marked the formal introduction of machine learning, deep learning, and artificial intelligence (AI) into the field of data science. Over the last decade, these technologies have generated advancements ranging from personalized shopping and entertainment to self-driving vehicles, as well as all the insights needed to effectively bring these real-life AI applications into our daily lives (Dataquest, 2021).

By the year 2018, new laws in the area were one of the most significant features of the progress of data science. In the 2020s, more advancements in AI, machine learning, and an ever-increasing demand for competent Big Data specialists is being envisaged (Dataquest, 2021).

Future trends in data science

Given the extent to which data and data science today dominate our society, we might properly question, "Where do we go from here?" What does the future hold for data science? While it's tough to predict what the future's breakthroughs will be, all signals point to machine learning's crucial relevance. Data scientists are looking for methods to leverage machine learning to create more intelligent and autonomous artificial intelligence (Gumbs, 2021).

In other words, data scientists are working diligently to advance deep learning technology in order to make computers smarter. These advancements may result in sophisticated robots combined with strong AI. Experts anticipate that AI will be able to comprehend and interact with humans, self-driving vehicles, and automated public transit in a world that is more linked than ever before. Data science will enable this new world to emerge. On the bright side, we may be witnessing the dawn of an era of substantial labor automation in the near future. This is projected to transform the healthcare, banking, transportation, and defense sectors (Joshi, 2021).

Current components of medical education

,Medical education refers to the formal training and educational process that prepares individuals to become medical professionals, such as doctors and physicians. It encompasses the knowledge, skills, attitudes, and behaviors necessary for the practice of medicine. Basic medical education typically starts with a pre-medical undergraduate degree, followed by a medical degree program, such as the Doctor of Medicine (MD) or Bachelor of Medicine, Bachelor of Surgery (MBBS).Competency-based medical education (CBME) has gained attention in recent years, focusing on the development of specific competencies or skills rather than traditional time-based models. It allows for individualized learning and assessment (Frank, 2015).

Clinical training is an essential component of medical education, where students gain practical experience under the supervision of experienced healthcare professionals. Simulation-based medical education has become increasingly prevalent, providing a safe environment for students to practice clinical skills before interacting with real patients (McGaghie, 2011).

Overview of medical education in Nigeria

A curriculum that was acquired from the British parent universities 60 years ago is being used in the majority of Nigerian medical schools (Ibrahim, 2007; Osoba , 2021). Since its inception in 1948 at the University College Hospital (UCH), in the city of Ibadan (in the southwest of Nigeria), undergraduate medical education in Nigeria has not changed. Following this, majority of our modern medical schools adopted the older medical schools' curriculum, which was created using standards and a curriculum that were identical to those of British institutions, with little or no modification (Federal Ministry of Health, 2012). The National Universities Commission (NUC) and the Medical and Dental Council of Nigeria (MDCN) have continued to oversee the supervision of undergraduate medical education. Thirty seven out of the forty-four government-approved medical schools and colleges have full accreditation to offer various medical courses. According to the MDCN data, the thirty seven medical schools only have a carrying capacity of 3,530 per year (Medical and Dental Council of Nigeria,2022). The Joint Admission and Matriculation Board (JAMB) and individual universities typically administer the university tertiary matriculation examination (UTME) for applicants to first-year programs and the Direct Entry (DE) program for applicants to second-year programs. To further evaluate applicants before they are matriculated into universities, some universities also hold post-UTME tests (Adeniyi, 1998; Osoba , 2021).

The typical length of the 6-year Bachelor of Medicine and Bachelor of Surgery (MBBS) degree program in Nigeria is split as follows: The pre-clinical program in basic medical sciences lasts 18 months, during which time students take courses in human anatomy, medical biochemistry, and human physiology. The remaining 42 months are spent taking pathology and pharmacology courses before moving on to the core clinical courses in medicine, surgery, obstetrics and gynecology, community medicine, and psychiatry (Malu,2010). After completing their undergraduate studies, medical graduates must complete a one-year required internship and one year of National Youth Service (NYSC), when they

are typically sent to distant places to provide community services. This is a requirement for further medical education to continue at federal or state institutions and is constitutional.

Challenges associated with medical education in Nigeria

Skewed admission policies: Many intelligent and aspirant undergraduates who are looking forward to a career in medicine are diverted by specific catchment-based selection practices. This is typically due to the tribal preferences of students from the state where the medical school is located or to factors that only those with power over the admissions process are aware of (Nto, 2019; Osoba , 2021).

Over-admission: Over the years, the excessive number of medical students admitted has had a detrimental effect on the medical school system in two ways. Firstly, the quality of instruction and learning is lowered by this overcrowding. Only a fixed number of students may be accommodated by the infrastructure and human resources already in place in order to maintain minimal training levels. The National Universities Commission (NUC), which is in charge of providing quality education in Nigeria, has established quotas for the admission of medical students into medical schools based on factors like staffing levels, infrastructure, and funding for facility expansion or renovation, among others. Secondly, institutions that are well aware that they have surpassed their quota for medical school entrance push students into undesired courses if they do not satisfy a "created" cut-off at the first-year (100 level) stage. This causes people who still want to study medicine to prolong their academic path. When students are rejected from moving forward with their chosen career path after being admitted to study medicine at the UTME/POST-UTME level, it also causes psychological and emotional anguish to the students and their families (Osoba, 2021).

Bogus pre-medical foundational knowledge: It is known that lecturers from faculties other than the Faculty of Basic Medical Sciences instruct medical students during the pre-medical phase. As a result, courses that are unrelated to the foundational stage of medical learning frequently take precedence over other, more crucial components of medical education needed to become a successful doctor. This means that pre-medical students who want to become doctors must take unnecessary classes like botany (Osoba, 2021).

Over-reliance on other faculties: Basic medical science courses are frequently taught by non-doctors, much like pre-medical education, which is taught by other faculties. The cornerstone of medical knowledge is the fundamental medical sciences, hence it must be presented in a therapeutically relevant way to ensure maximum retention and later application of this information. Medical education is a distinct specialty, and the majority of those who teach it lack formal training (McKimm, 2009). Due to the fact that the fundamental medical sciences were not taught in a clinically oriented way, this results in a deficiency in the quality of performance of medical students in the clinical class and subsequently during residency (Osoba, 2021).

Lack of update of medical curriculum: Medical students who finally complete their residency program in industrialized nations may not be familiar with many recent scientific and technical discoveries since the medical curriculum is out of date. The possibility that Nigerian medical school graduates lack the abilities and skills essential to succeed in the evolving practice environment of the twenty-first century is extremely concerning (Silver,1990). Most

Nigerian-trained physicians must relearn their traditional habits and pick up new ones in order to work well in other environments.

Deficit in learning Infrastructure: The Nigerian medical school system seldom ever makes advantage of emerging instructional tools like mannequins, role playing, and simulations among others. Due to the fact that some of the topics being taught require students to use their imagination, this impedes practical learning and may worsen their comprehension.

Excessive burden on the clinical teacher: The foundation upon which the medical system is formed is the clinical educator. The teacher is required to educate, provide medical treatment to patients, do research, and perform other administrative duties in subpar settings, which lowers the quality of the clinical teacher. In addition to them, the clinical instructor receives little pay despite sometimes ill-defined work hours. These lead to a teacher who is physically and psychologically exhausted and who, at best, is only motivated to teach to an inadequate level. With the current brain in Nigeria, the pressure on those left behind is getting worse.

Inadequate exposure to high impact research: Nigeria uses research findings from industrialized nations, and while some of these discoveries have aided in the improvement of healthcare, others have fallen short since they are not relevant to the country's circumstances (Awofeso, 2020). As part of the mandatory graduation requirements, students are introduced to and supervised to do research projects for the first time during their last year of study at the majority of Nigerian medical schools. Due to the fact that most students view these projects as graduation requirements rather than an essential component of medical education, many students fail to get the necessary information and are unable to develop their research abilities in such a short amount of time. This invariably results in physicians with poor research abilities and hinders the growth of medicine in the nation.

Assessment in medical pedagogue: Given the diversity of medical education, it might be challenging to evaluate clinical expertise fairly. However, Harden established the Objective Structured Clinical Examination (OSCE) in 1975 as a substitute for the current techniques for evaluating clinical performance (Harden, 1975). It evaluates medical students' abilities in simulated clinical settings. Although this approach is objective and assesses the cognitive and psychomotor abilities of the medical students, it has not been able to measure the candidates' communication and ethical reasoning abilities, which are essential traits of a medical practitioner (Sholadoye,2019). As a result, this tends to produce clinicians with weak interpersonal skills, poor ethical judgment, and poor patient management empathy.

Integration of Technology and medical education

The integration of technology in medical education has expanded, with the use of virtual reality (VR), augmented reality (AR), and online learning platforms. Online learning platforms and massive open online courses (MOOCs) have facilitated access to medical education resources and enabled distance learning opportunities (Dong, 2015; Sanders, 2013). Inter-professional education focuses on collaborative learning among healthcare professionals from different disciplines to improve patient care. It aims to enhance communication, teamwork, and understanding of each profession's role (World Health Organization, 2010).Certification bodies, like medical boards and licensing authorities, ensure that medical graduates meet the required standards and competencies before practicing

medicine independently (Norcini,2003).In Nigeria, the medical and dental council of Nigeria (MDCN) is the certification board for medical practice.

Data science applications in medical education

Data science has found numerous applications in the field of medical education, revolutionizing the way students learn, researchers analyze data, and educators make informed decisions. Some specific areas where data science has been applied in medical education include the following;

Predictive Analytics for Student Performance: Predictive analytics utilizes historical data to predict student performance and identify at-risk students who may require additional support. It helps educators personalize learning experiences and improve outcomes. A recent study applied predictive analytics in medical education to predict student performance using data from electronic health records and course evaluations (Khan, 2021). Another researcher Su(2022) mentioned in a similar study that forecasting student achievement is crucial in areas of higher education as well as deep learning and its connection to educational data. Predicting student success helps in course selection and developing appropriate future study plans for students. Aside from anticipating student performance, it supports teachers and management in monitoring students in order to provide support and combine training packages for the best results. One advantage of student prediction is that it reduces official warning signals as well as student expulsions owing to inefficiency.

Prediction helps students choose the optimal courses and study regimens for their abilities. In their paper, they proposed approaches for predicting using a deep neural network by extracting meaningful data as a feature with suitable weights. To automatically generate neural networks, many updated hidden layers were employed; the number of nodes and hidden layers was limited by feed forwarding and back propagation data from previous cases. The system was trained using labeled data from the dataset in the training mode, and it was evaluated in the testing mode (Su,2022).

Virtual Patient Simulations: Virtual patient simulations provides realistic scenarios for medical students to practice clinical decision-making. Data science techniques are used to create dynamic and responsive virtual patients. A study by (Ellaway, 2020) explored the use of data science and artificial intelligence in developing virtual patients and enhancing the realism and educational value. Kononowicz (2019) said in another study that virtual patients are interactive digital simulations of clinical settings for the goal of health professional education. He conducted a systematic study to assess the effectiveness of virtual patients in health professional education to traditional education, blended traditional education, other forms of digital education, and design variants of virtual patients. Knowledge, skills, attitudes, and satisfaction were the outcomes of interest. The technique entailed conducting a systematic study using Cochrane methodology on the usefulness of virtual patient simulations in pre- and post-registration health professional education. They looked through seven datasets from 1990 to September 2018. There were no language limitations. There were randomized controlled trials and cluster randomized trials among them. They chose research independently, extracted data, assessed the possibility of bias, and then compared the information in pairs. When required, they also contacted research authors for more information. All of the pooled analyses used random-effects models.

Their inclusion criteria were satisfied by 51 studies with a total of 4696 individuals. In addition, 25 research compared virtual patients to conventional education, 11 studies analyzed virtual patients as blended learning, 5 studies compared virtual patients to other kinds of digital education, and 10 studies evaluated different design variants. The pooled analysis of trials evaluating the effect of virtual patients on knowledge (standardized mean difference [SMD]=0.11, 95% CI -0.17 to 0.39, I2=74%, n=927) and skills (SMD=0.90, 95% CI 0.49 to 1.32, I2=88%, n=897) favored virtual patients. Surveys with item-by-item comparison were commonly employed in studies evaluating attitudes and satisfaction.

There were not enough trials comparing virtual patients to various types of digital instruction and design variants to make firm recommendations. Several methodological shortcomings and variability in the included studies lead to a low overall quality of evidence.

The authors found that low to moderate evidence and mixed data show that, as compared to traditional education, virtual patients can more successfully enhance skills and, at the very least, knowledge. Clinical reasoning, procedural skills, and a combination of procedural and team skills increased. They discovered indications of efficacy in both high-income and low- and middle-income nations, indicating virtual patients' worldwide applicability. Further investigation into the efficacy of several design variants of virtual patients was proposed.

Adaptive Learning Systems: Adaptive learning systems tailor educational content and delivery based on individual learner needs and performance. Data science algorithms analyze student data to identify knowledge gaps and recommend personalized learning materials. A recent review by (Schwartzstein, 2022) discussed the applications of adaptive learning systems in medical education and highlighted their potential benefits. Kellman (2013) stated in a previous research that breakthroughs in the learning sciences have the potential to significantly improve medical education and maximize the advantages of developing medical technology. Perceptual learning (PL) and adaptive learning technologies are two key areas of innovation in the learning sciences that relate to simulation and other parts of medical learning, according to his study. He claimed that PL technology provides systematic, computer-based approaches for teaching pattern identification, structural intuition, transfer, and fluency for the first time. New adaptive learning technologies that maximize learning for each person, include objective evaluation, implement mastery criteria and are synergistic with PL. The author described the Adaptive Response-Time-based Sequencing (ARTS) system, which guides spacing, sequencing, and mastery depending on each learner's accuracy and speed in interactive learning. These innovative technologies have recently been used in medical learning contexts, such as adaptive learning modules for initial medical diagnosis and perceptual/adaptive learning modules (PALMs) in dermatology, histology, and radiology. All of these initiatives point to the amazing potential of perceptual and adaptive learning technologies to improve learning in a range of medical areas, both separately and in combination (Kellman, 2013).

Learning Analytics: Learning analytics involves the collection, analysis, and interpretation of data generated during the learning process (Kleimola,2022). It helps educators gain insights into student behavior, engagement, and learning progress. According to Johar (2023) in a recent research, learning analytics delivers statistical analysis and derives insights from data, notably in education. He also mentioned that several research on student involvement in online learning have been undertaken at tertiary institutions to validate its benefits on students' learning performance. There is, however, a knowledge vacuum in that the sorts of

student-engagement difficulties emerging from learning analytics have not been researched together thus far. Their work used a novel systematic literature review (SLR) to analyze 42 papers utilizing Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to overcome the knowledge gap. He noticed that previous research on student involvement in online learning does not fully incorporate the five categories of online engagement outlined by Redmond et al., and the application of learning analytics on the subject is similarly restricted. Based on this, they conducted a review in order to shed light on the many forms of student engagement suggested by learning analytics, with the goal of improving students' learning performance in online learning. Their findings revealed that while some research examined multimodal involvement to improve students' learning performance, the number of studies was restricted. They suggested that future study encompass multiple involvement in online learning, such as social, cognitive, collaborative, behavioral, and emotional engagement, and that learning analytics be used to improve students' learning performance.

Data-Driven Curriculum Design: Data science can inform curriculum design by analyzing student performance data and identifying areas for improvement. Educators can use data-driven insights to optimize the curriculum and enhance learning outcomes. A recent publication by Yeh et al described a data-driven approach to curriculum evaluation in medical education, providing evidence-based recommendations for curriculum redesign (Yeh, 2021). Han (2019) noted in a previous research that medical education must adapt to various health care contexts, such as digitalized health care systems and a digital generation of students in a hyper-connected society. Their study's goal was to identify and synthesize the principles that medical educators must incorporate into their curriculum, as well as to propose sample educational programs.

To incorporate data from multiple study designs, an integrative review was undertaken. Between 2011 and 2017, they looked for publications in PubMed, Scopus, Web of Science, and EBSCO ERIC. Their main search phrases were "undergraduate medical education," "future," "twenty-first century," "millennium," "curriculum," "teaching," "learning," and "assessment." They selected and retrieved them from titles and abstracts based on inclusion and exclusion criteria. To establish an agreement on the themes and subthemes, all authors read the whole texts and debated them. A modified Hawker's assessment form was used to appraise the data.

Among the 7616 abstracts initially identified, 28 full-text articles were selected to reflect medical education trends and suggest suitable educational programs. The integrative themes and subthemes of future medical education were as follows: 1) a humanistic approach to patient safety that involves encouraging humanistic doctors and facilitating collaboration; 2) early experience and longitudinal integration by early exposure to patient-oriented integration and longitudinal integrated clerkships; 3) going beyond hospitals toward society by responding to changing community needs and showing respect for diversity; and 4) student-driven learning with advanced technology through active learning with individualization, social interaction, and resource accessibility.

They came to the conclusion that the thorough programs presented in their study may be valuable for medical educators in developing curriculum. More study was needed, however, to incorporate educational trends into graduate and continuing medical education, as well as

to evaluate the status or impacts of innovative educational programs in each medical school or environment (Han, 2019).

Artificial intelligence and undergraduate medical education

In his review, Lee (2021) opined that artificial intelligence (AI) is a fast increasing phenomena set to cause large-scale changes in medicine. However, medical education has lagged behind AI's fast breakthroughs. Despite many calls to action, AI education in undergraduate medical education (UME) has been slow to take hold. His scoping research sought to identify gaps and major themes in the peer-reviewed literature on artificial intelligence training in undergraduate medical school.

The research was a scoping review, and the approach of Arksey and O'Malley was used. Between January 2000 and July 2020, seven electronic databases, including MEDLINE and EMBASE, were searched for papers concerning the integration of AI in UME. Three co-investigators independently examined a total of 4,299 publications, and 22 full-text papers were included. A systematic checklist was used to extract data. Iterative thematic analysis was used to identify themes.

The findings revealed that literature addressed the following topics: (1) the need for an AI curriculum in UME, (2) recommendations for AI curricular content such as machine learning literacy and AI ethics, (3) curriculum delivery suggestions, (4) an emphasis on cultivating "uniquely human skills" such as empathy in response to AI-driven changes, and (5) challenges with introducing an AI curriculum in UME. However, there was significant variation and lack of agreement between studies in terms of AI curricular content and delivery.

The study concluded that despite the large volume of literature, there is little consensus on what and how to teach AI in UME. Further research is needed to address these discrepancies and create a standardized framework of competencies that can facilitate greater adoption and implementation of a standardized AI curriculum in UME.

Conclusion

Data science application in medical education is rapidly evolving. Current frontiers in data science application in medical education include Predictive Analytics for Student Performance, Virtual Patient Simulations, Adaptive Learning Systems, Learning Analytics and inclusion of artificial intelligence in medical curriculum. There is low to modest and mixed evidence to suggest that when compared with traditional education, virtual patients can more effectively improve skills, and at least effectively improve knowledge. There is a potential of perceptual and adaptive learning technologies, individually and in combination, to improve learning in a variety of medical domains. The studies reviewed so far show that there is little consensus on what and how to teach artificial intelligence in undergraduate medical education.

Recommendations

1. Further research is suggested to address discrepancies and create a standardized framework of competencies that can facilitate greater adoption and implementation of a standardized artificial intelligence curriculum in undergraduate medical education.

2. Future research should incorporate multifaceted engagement such as social, cognitive, collaborative, behavioural, and emotional engagement in online learning and utilize learning analytics to improve students' learning performance.

3. Further research is required to integrate the educational trends into graduate and continuing medical education, and to investigate the status or effects of innovative educational programs in each medical school or environment.

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