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Review Article

The future of radiology education and training: a vision for future training models

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ABSTRACT

This article discusses the history and future direction of radiology education and training. Beginning with the historical progression from Röntgen's discovery to the digital era, it highlights the limitations of traditional apprenticeship models and the need for competency-based learning. Education today focuses on the incorporation of simulation, AI, VR/AR, and teleradiology, revolutionising how radiologists learn technical as well as decision-making skills. Some of the key issues are workforce shortages, differences in training, burnout and lagging adoption of innovations. The paper also explores evolving skill needs data analysis, communication, ethics, and collaboration as essential competencies for contemporary radiologists. It proposes a personalised and technology-driven curriculum supported by global collaboration, continuous faculty development, and standardised accreditation. In conclusion, the research provides that the future of radiology education is in integrating technological innovation with human-centred care, developing flexible, reflective professionals who can excel in an AI-integrated healthcare setting.

Keywords: Radiology education, Competency-based training, Artificial intelligence, Simulation and VR/AR, Future skill development

INTRODUCTION

The latest medical report analysis has confirmed that, as the diseases are spreading so rapidly, Radiology is just like a boon for diagnosing several diseases, planning treatment and demonstrating life-saving processes.[1] With advanced technologies such as CT, MRI, ultrasound, interventional radiology and molecular imaging, radiologists can help detect diseases and support doctors in making better decisions. Radiology not only supports areas such as Digital Imaging, Teleradiology and Global Sharing of medical information, but also makes healthcare sharper, complex and precise.[2] Today, radiologists need to participate in team discussions and handle emergencies to upgrade their skills, as this helps doctors make more precise and accurate diagnoses. The department and duties of radiology have evolved significantly; however, we need to upskill the future generation of radiologists so that they can evolve and become pillars of the complexities of the medical field.[3] Most training programs involve watching, learning and then doing it yourself. This "see one, do one, teach one" approach dates back over 100 years and does not adequately equip students for the contemporary challenges that they will encounter.[4] Additionally, conventional instruction tends to focus solely on technical know-how, often erasing other essential capabilities, such as communication, decision-making, professionalism, and adaptability in dealing with new technologies. To upskill with these changing dynamics, radiology education must employ contemporary equipment like PACS (Picture

Archiving and Communication Systems), handheld computers, web-based case collections, and simulators. This pre-existing equipment is hardly applied in the training programs. Research has established that interactive and digital learning approaches can enhance students' problem-solving skills more effectively than conventional techniques. However, to make use of the rich learning and experience of reflection and authentic challenges, competence alone isn't enough. We need to think ahead and not only train students to simply mark boxes on a list of skills. Simulation-based training is the need of the hour, which not only allows students to practice actual procedures under safe conditions but also ensures that to receive immediate feedback and work repetitively until they attain surety. Similarly, just as pilots practice in simulators before flying actual aircraft, radiologists can practice in these simulators to prepare for emergencies without compromising patient safety.[5]

This article will consider how radiology training needs to make amendments to accommodate future needs. It will emphasise the need for an upgradation of training practices, balancing outdated experience with new aids, and creating a system that generates not only competent radiologists but reflective, skilled, and versatile professionals.

Historical perspective

Radiology came into existence in 1895, when Wilhelm Röntgen discovered a new type of ray called X-rays.[6] This was a pilot project in medical imaging. At that time, no one knew how to use it properly, so people of different backgrounds - such as electricians, photographers and doctors used it. Radiology technology has since then advanced rapidly. MRIs, CT scans, digital X-rays and ultrasound were tools that were being used very frequently. However, the training of radiologists has not been upgraded and has shown little advancement. The majority of radiology reports were still handwritten or dictated and frequently lacked structure, despite the increasing digitalisation of machines.[7] A major change occurred in 1922 when Dr Preston Hickey, a radiologist, proposed that physicians seeking to become members of the American Roentgen Ray Society submit 100 sample reports for zevaluation.[8] He further suggested establishing a uniform framework for writing reports. Despite being one of the first significant turning points in radiology education, this was disregarded for over 80 years. RadLex, a standardised language tool, was only recently adopted by radiology to enhance radiology education and practice. It was only around the 1990s and 2000s that radiology gained popularity and competitiveness. Medical students were made adept at the newer technologies; a new gate opened with lucrative career opportunities in this field. The surge was witnessed in 2009, when about 7% of U.S. medical students applied to radiology residency programs.[9] Ironically, the interest from medical students took a downward shift. Artificial Intelligence (AI) has become a huge deterrent, due to which students have been uncertain about their job security in radiology in the future. One key point to remember here is that radiologists have been actively dealing with AI for 40 years, even in medical imaging recognition and classification. Since then, we have come a long way in terms of AI advancement in the radiology field. AI can play a key role in identifying tumours or bleeding, fractures, even more precisely than human capabilities is being looked at as a support tool rather than a replacement. A tool with more precise results in a shorter time span. This, however, in no way eradicates the many concerns that medical students might have. In a recent study, 26% of the respondents who did not select radiology stated their sole reason to do so as AI. The already thriving radiologists do not seem so worried. However, they are more concerned about "turf losses" that represent other specialities, such as cardiology or neurology, taking over radiology tasks, such as heart scans or brain imaging.[10] The current-day educators firmly believe that the big step ahead is to introduce AI and its applications in radiology education from a very early stage. Educating the students about AI in the nascent stages could make students much more adept at dealing with AI. This is being looked at as a dynamic shift in how we train our future radiologists Figure 1).

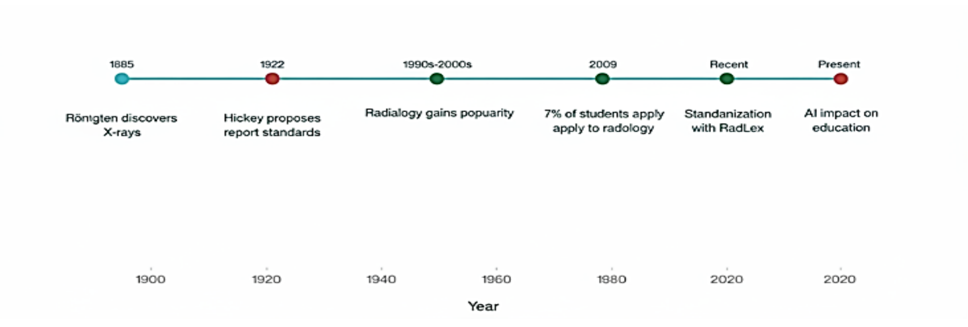

Figure 1: Evolution of radiology education: key milestones from discovery to AI Integration.

Current state of radiology education

A major change is currently underway in the field of radiology education. The process has become overly long. The expert community increasingly agrees that the traditional five-to-seven-year training period is too lengthy.[11] Leading organisations in radiology, including the RSNA, ACR, and American Board of Radiology, have called for a streamlined five-year training program. This proposed plan allocates 3.5 years for core radiology, including six months of clinical time, followed by a 17 ACGME-accredited fellowship.[12] This change reflects the impracticality of educating all residents in every subspecialty. Once again, in the UK, medical training has shifted from what were, in essence, apprenticeships to straightforward competency-based training culminating in a Certificate of Completion of Training (CCT).[13,14] Such a transition was driven by initiatives like Calman and Modernising Medical Careers. While structuring these new models increases the standardisation and transparency of assessments, it may also limit the development of subtle skills and tacit knowledge that were traditionally cultivated within the master-apprentice model. Apprenticeship-like structures are being replaced by explicit demonstration and documentation of competence over time. Other organisations such as JRCERT, JRCNMT, ARRT, NMTCB, and ARDMS play important roles in ensuring that educational programs maintain high standards for credentialing and ongoing competence. Additionally, simulation-based training and assessment are gaining popularity, with formal recognition from organizations such as the American College of Surgeons.

Technology is also revolutionising the way radiology is taught and learned. Teaching programs are gradually introducing digital tools, including e-learning, remote patient chart access through PACS/EMR, PDAs for data management and high-fidelity simulation technology for teaching and assessment. Concurrently, international collaboration is thriving through web-based learning modules and good-quality videoconferencing, creating a global community of lifelong professional development.[15,16]

Challenges in contemporary radiology training

Radiology education in today's world has a multitude of challenges impacting both learning and practice.[17] One of the most challenging issues is the increasing volume of scans and their level of complexity. The volume of imaging studies and the complexity of interpreting them have grown rapidly in the past decade, placing greater demands on radiologists' time and expertise.[18] At the same time, technologies like thinner CT slices mean more scans per patient over time, which leads to an increase in workload. The burden is defined by radiologists aptly as being that increased volume, complexity, and criticality of examinations add additional time and medicolegal constraints. Another hot potato is workforce deficiency and burnout.[19] Needless imaging adds to this stress, with "over 80 million CT scans annually throughout the United States, 30% are calculated to be unnecessary". Burnout is again highlighted with the fact that stress, in some instances leading to 'burnout,' is a crucial yet underserved factor impacting productivity. Training variation across the world is another challenge. It has been highlighted that differences in training curricula and resources result in differing skill levels among radiologists globally. Differences in practice also occur, as inappropriate imaging rates are high and vary widely across various regions. Standards of reporting also vary, as convincing radiologists to forego free-text reports in favour of structured reporting is the greatest hurdle. In addition, adoption of innovations is sluggish because, on average, it takes 17 years for health care innovations to become adopted in clinical practice.[20]

Lastly, interprofessional education remains limited. It was pointed out in one paper that opportunities for radiologists to train alongside other healthcare professionals remain limited, which can hinder effective multidisciplinary collaboration.[21] Electronic collaboration is proposed to enhance this, with a suggestion to provide electronic consultations among radiologists, technologists, and clinicians. Developing closer partnerships is essential, as radiologists differentiate ourselves by integrating multimodal data with other information specialists, such as pathologists.[22] New technology also requires wider collaboration, but current radiology curricula rarely include structured interdisciplinary training (Figure 2).[23,24]

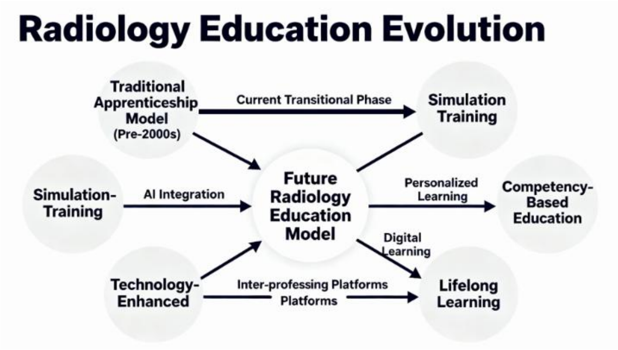

Figure 2: Transformation pathway of radiology education from traditional to future models.

Integration of technology in radiology education

Technology has emerged as the most critical tool of radiology education in recent years, transforming the way students learn and instructors teach.[25] Artificial intelligence (AI) and machine learning (ML) are increasingly being integrated into radiology curricula since these technologies are utilised for image analysis, workflow assistance, and even report generation.[26] Medical students, through surveys, have emphasised that they should be taught AI right from the beginning of training to eliminate the fear of losing their jobs as radiologists and instead teach them to work in conjunction with it. Experts predict machine learning as a force of change that can remodel radiology entirely, indicating how crucial it is for trainees to learn to make changes early on AI has also been termed as a key tool that is capable of assisting radiologists by enhancing image reconstruction, dealing with large data volumes, and aiding in clinical decision-making, making it critical in future training. Simulation training is yet another innovation in education.[27] Learners can practice imaging interpretation and interventional skills on simulators in a protected environment before working with actual patients.[28] Research reveals that simulation is not only beneficial for technical competence but also for the confidence and decision-making skills of students. Simulation techniques are also associated with patient safety, as they enable trainees to train on challenging tasks without causing harm to patients. Virtual reality (VR) and augmented reality (AR) are also becoming integrated into instruction. These technologies provide students with a 3D representation of anatomy and pathology, making it simpler to comprehend intricate structures.[29] Literature illustrates that VR and AR are already being experimented with in anatomy and interventional radiology instruction, enhancing the learning process for trainees as opposed to traditional methods. Other reports add that interactive VR and AR experiences increase radiology learning's interactivity and engagement, which encourages students to learn more effectively.[28]

Teleradiology and learning platforms at a distance have also revolutionised training. They enable sharing cases and reports between distances, and radiologists and students can collaborate even from foreign countries.[30] Students also identify that teleradiology will revolutionise the profession by enabling remote consultation and global learning. The revolution in radiology has also opened doors for online learning, videoconferencing, and e-lectures that can substitute traditional classroom instructions.[31] During the COVID-19 pandemic, these internet systems demonstrated that it was possible to keep radiology education running effectively without any face-to-face instructions.[32]

Shifting skills sets and competency requirements

The evolving landscape of radiology calls for an inventive shift in core skills dominated by technological growth and emerging healthcare needs. One line of evolution is the growing emphasis on data science and informatics radiologists increasingly need to supervise digital imaging systems, computer-based patient records, structured reporting and AI-enabled workflows. Skills have also broadened from only picture interpretation to data management, standardised vocabularies like RadLex and machine learning dataset creation.[33] The fusion of AI, PACS, and big data analytics for clinical decision-making requires radiologists to read complex multimodal data and make decisions based on quantitative information.[34]

Communication and collaborative multidisciplinary work have also become key foci in the shift of radiologists from stand-alone image readers to being participative members of clinical teams 21. Domestically, the use of international databases via MIRC and telemedicine schemes allows worldwide collaboration and transfer of cases, co-facilitating an interdisciplinary approach. We are seeing that radiologists are involved in tumour boards with multidisciplinary teams, pre-surgical planning with 3D imaging and being consulted by clinicians to enable seamless transfer of information and coordinated care delivery. Another consideration is greater training of communication skills, to prevent medico-legal risks due to miscommunications and delays in reporting.[35]

Ethical, professional, and patient-centred practice are essential components of the current radiology practice. The push towards direct communication with patients, the concept of informed consent and transparency especially in AI-based decision-making for diagnosis highlights radiologists' duty and moral responsibility. Simulation-based training and competence testing promote patient safety by displacing practice that is based on the acquisition of skills "practised on patients" Such initiatives, including ACR's Imaging 3.0, highlight the role of radiologists' visibility and engagement with patients in improving trust and safeguarding professional identity. [5,36]

Personalized and competency-based education models

Simulation-based teaching is fundamental to this model of training, allowing trainees to learn the technical precision in a safe, controlled environment before applying it to patients. Sonography and interventional simulators are increasing in use to identify the need for improvement, and then practice to mastery under the principles of CBME, with its emphasis on attainment of outcomes: patient safety.[37] The paradigm of education in radiology is transforming to one that has a personalised and competency-based perspective, which reflects the broader shift in medical educational philosophy. CBME is predicated on the demonstration of capability as opposed to clock hours in training. However, there is concern that rigid, task-based models may (if implemented less than ideally) obstruct higher-level thinking, intuition and professional judgement, preventing average performance from excellence instead of the bare minimum. The move to adaptive learning and modular teaching suits the varied journeys of trainees. Initiatives such as the Radiology-Integrated Training Initiative and online resources allow student-led learning, independent of time, with self-assessment encouraged and opportunities for further study in subspecialty modules contributing to autonomy and motivation.[31] Options such as Tooke and MMC-style reforms, favouring wide core programmes with exit into specialisation thereafter, recognise that diverse career paths (both clinical & research-based) require tailored pathways. The use of electronic resources and the creation of modular paediatric digital curricula demonstrate how these types of tools can support continuous, just-in-time learning: there is ongoing relevance to emerging technology and subspecialty requirements. Online systems of assessment now track performance over time and are no longer based on subjective feelings. H+ Workplace-based assessments and ongoing digital records of trainees' learning encourage accumulation year by year, becoming logbooks, procedural diaries, evidence of reflection rather than exam marks. Although logbooks have limitations, new digital tools, for example, MIRC, provide a platform upon which full portfolios can be built to show continuous competence and readiness for unsupervised practice.[38,39]

Global perspectives and disparities

The state of radiological education in the world today is an amalgam of progress, disparity, and aspiration. The variations in models of training show an incomplete evolution of education. In the UK, for instance, formalised competence-based models largely following European and American trends have led to increased formalisation in some markets, while others are still characterised by traditional apprentice-type systems with little or no use of modern methods.[40] These contrasts are also found in new disciplines such as AI and simulation training, according to which some Western countries tend to integrate disruptive technologies very early, versus others, like France, where the teaching of AI was only initially proposed a short time ago for radiology residents. These discrepancies reflect the extent to which geography continues to shape opportunity. In spite of such diversity, a common global push towards creating unity exists. There is a growing trend towards harmonisation and international cooperation spearheaded by global radiology societies like RSNA and CIRSE that are championing shared digital platforms, open-access teaching libraries, and collaborative simulation activities.[41-43] International task forces and conferences stress the imposition of common principles, particularly in new areas like AI, calling for readiness collectively for an ever-changing future. But at the heart of these partnerships is closing educational gaps. The knowledge void is being filled online, as demonstrated by R-ITI and MIRC attempting to redress the resource imbalance by making quality learning content available beyond well-resourced academic establishments.[44] However, such a move leaves deep inequalities in places which have shortages of workforce and poorly established training facilities, where there is no access to mentoring, technology and advanced curricula. Trepidations regarding the risk of radiology education being reduced to a “minimum competency” rather than aspiring for excellence resonate within a wider call for aspirations and inclusion into training.[45,46]

Future direction and innovations

A future for radiology education is gradually emerging, fuelled by accelerating technology and the evolving landscape of health provision across global healthcare markets.[26] The essence of it is the concept of lifelong learning, and recognising that as radiologists we need to keep our knowledge going to stay on top. Educational ‘apps’; online examination tools, independent learning materials such as ELERA and COMPARE Radiology have allowed individuals to progress at a pace free from the requirements of formal education programmes.[47,48] With recertification and maintenance of certification being embedded in professional life, continuous development has become a duty rather than an option. This journey has also been complemented by the development of simulation-based training, which supports skill-learning through repetition in patients at risk. Educational models are transforming towards "hybrid" models that leverage well-tested mentorship blended with innovative digital technology. Technology is employed to assist teaching rather than substitute for it. Case-based discussions, consult rounds, and image libraries have been supplemented by virtual modules and simulation laboratories with the inverted classroom model: online foundational learning is developed that is deepened interactively in practical orientations. The hybrid arrangement enables pretraining preparation and more fully immerses the hands-on training.[49]

In the future, radiologists will need to be prepared not only as image readers but as system participants in healthcare ecosystems of tomorrow. There are increasing expectations on shifting the curricula towards general skills, eg., leadership, ethics, AI fluency, healthcare economics and cross-disciplinary working. At an international level, networks such as MIRC and Internet2 are designing learning environments to be consistent with the globalised nature of modern healthcare, preparing radiologists for telemedicine and evidence-based practice. Though artificial intelligence (AI) continues to move the needle on workflow efficiencies, the radiologist of the future who is adaptable to change, works with innovation and embraces lifelong learning will propel the next generation of patient-centred care.[50]

Recommendations and strategic roadmap

At both national and global levels, strategies are required to make radiology training more standardised and future-ready. Policymakers must also address variations across regions because inappropriate imaging rates vary widely across regions. Governments and professional organisations should update their accreditation standards, mandating that new modalities like AI and simulation be included as a part of the program curriculum. Reporting also requires more structured organisation and standardised language as these significantly enhance safety and uniformity across institutions. Since health care innovations take, on average, 17 years to realise full adoption into practice, new pathways to more rapidly implement policies should be undertaken through revised training.[51] It is the responsibility of training institutions hospitals and universities to support educators in transitioning to new learning methods. Focused objectives must be supported by simulation and digital pedagogy platforms because simulation-based training has been used to maximise patient safety and ensure trainee competence. Institutions should start to consider creating ongoing faculty development programs that allow training staff to become familiar with new imaging technologies and artificial intelligence. Teleradiology and other online collaborative tools can also enhance access and facilitate the sharing of expertise.[2] Networks are capable of sending broadcast-quality video streams. Faculty need to be supported to learn how to communicate effectively and produce more patient-centred and standardised reports. The field of Radiology is lacking educational research to assess the impact of educational innovations on learning and clinical outcomes. It is essential for subsequent studies to address simulation environments and virtual training methods to help evaluate if there is a transfer to actual clinical skills.[28] AI-enabled learning platforms may help gather performance data on students and facilitate curricular modification. Another area for educational research is in multidisciplinary practice, as radiologists, we are distinct by integrating multimodal data with the expertise of other information specialists. Finally, studies are crucial to investigate the professional growth of trainees and the diagnostic accuracy linked to digital tools and technologies such as VR, AR and AI.[52]

DISCUSSION

This study linked the dots from Röntgen's mistake in 1895 to our age of AI and has shown that technology spirit ahead of education. The issues of the present do not support see one, do one, teach one.[53] Article highlights findings underscore the value of competency-based education, for which simulation-based training, AI and machine learning, as well as virtual reality tools, are adjuncts in the continuous goal of minimising patient harm and survival amongst healthcare educators in training a skill. Moving from interpret and report to the world of data science, informatics, integrative diagnostic and multi-disciplinary approach needs radiologists' knowledge on domain-organised structured reporting systems such as RadLex, PACS workflow, and patient-friendly communication standardisation.[54] Given global disparities in training resources, global cooperation through organisations such as RSNA and MIRC offers the promise of standardisation. But issues remain: a workforce shortage and burnout, too much imaging testing and the 17-year lag in applications of breakthroughs all warrant policy response now. The next generation will use mentoring and electronic tools, which will bring lifelong learning networks and individualised adaptive curricula. Instead of fearing the substitute, young radiologists should consider AI as a collaborator in learning and developing aspects of leadership, ethics and interdisciplinarity.[55] It is only through substantial reform that we can grow the reflective, nimble practitioners necessary for tomorrow's health care settings.

CONCLUSION

Radiology training is currently at a crossroads of innovation and tradition. From Röntgen's first X-ray to the age of AI, the transition has been a shift from plain image interpretation, with human limitations and variability inherent to an analogue world, from a one-dimensional medical discipline that disregarded technology and communication advances, that was intuition or experience-driven, to multidisciplinary support in technology, communication and evidence-based decision-making. Modern education is competency-based and features individualised learning supported by simulation, adaptive curricula, and computer-based assessments focused on patient safety and lifelong learning. A commitment from institutions, policy and educational leaders will be needed to incorporate AI/simulation in the curriculum, support faculty development initiatives and develop global resources for CPD if radiology is to advance. In the future, our radiologists will not only interpret images, they will also deal with data, work in multidisciplinary teams and work for technology rather than against it.

In essence, the future of radiology is all about training caring, adaptable and empathic physicians ready to shape the next era of patient-centred medicine.

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