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LITERATURE REVIEW

SIMULATION-BASED TRAINING FOR RADIOLOGIC TECHNOLOGIST STUDENTS IN SUDAN: A RESILIENT EDUCATIONAL APPROACH AMID CONFLICT AND RECONSTRUCTION

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ABSTRACT

PURPOSE: This paper discusses how civil war has disrupted medical and radiologic technologist students' hospital training in Sudan. It emphasises how, in conflict, developing clinical skills depends on simulation-based training.

METHODOLOGY: This paper studies and highlights satisfaction with simulation-based learning in routine X-ray radiography, using in-house tools developed globally, qualitative surveys, and feedback analysis.

FINDINGS: Simulation-based training improves clinical skills, visual thinking, and practical ability despite constraints, including limited technology and less patient contact. This paper shows that it is a useful substitute for conventional education, supporting Sudanese healthcare development and recovery.

CONTRIBUTION AND PRACTICAL IMPLICATIONS: This paper offers pragmatic solutions for sustainable development and recovery for Sudan's healthcare system, providing a good substitute for traditional training approaches. The strategy fits Sustainable Development Goals (SDGs) 16 and 3.

LIMITATION: Limited access to simulation tools and infrastructure in conflict-torn Sudan makes training challenging since there is a lack of funding and teachers.

KEYWORDS: *Simulation Training; Radiology; Sudan; Clinical Skills; X-Ray Tools; Conflict Education.*

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INTRODUCTION

Digital imaging systems have made significant inroads into the radiological workplace due to their substantial transformative benefits, including enhanced image quality, reduced radiation exposure to patients, and the capability for electronic image storage and manipulation. This evolution necessitates a paradigm shift for radiologic technologist students regarding the effective instruction of diagnostic radiography: specifically, this involves a reconceptualisation from the traditional film-based display paradigm to a digital format. Among various critical considerations essential to this transformation from film-based to digitised imaging, reputation modelling and detecting convolutions involved in the image formation process utilising an indirect digital detector, particularly in the context of angiographic images, have emerged as significant topics (Sujar*et al.*, 2022). Due to its advantageous characteristics, such as effective knowledge transfer and versatile application, simulation-based training is increasingly used to cultivate robust safety and protection behaviours before professionals undertake their responsibilities in actual work environments. Nonetheless, the implementation of simulation-based training concerning safety and protection across various disciplines remains relatively underexplored within the educational research of radiologic technologists, despite significant efforts from leading performance-oriented organisations to enhance this training.

Museum-based assessments have been extensively conducted within visual YouTube (YT) and visual light Cultural Heritage Information Systems (CHIS), engaging various art researchers, evaluators, novices, and audiences. These assessments focus on the perception of single or multiple images to comprehend meaning and cultural meaning generation and address ethical concerns related to child protection and privacy. Radiology colleges have begun exploring the use of an interactive teaching and learning virtual reality environment for educational research in diagnostic radiography.

Some researchers have proposed an interactive teaching and learning environment for diagnostic radiography. They have implemented a virtual X-ray imaging rendering library and a real-time patient positioning control system. High graphical realism enables users of X-ray diagnostic imaging to replicate their tasks. Furthermore, the efficiency is adequate to facilitate real-time interaction between users and their surroundings, allowing its application to extend to lectures by showcasing good and bad practices. It is proposed that the skills acquired from the simulated environment can be applied in the real world.

Radiologic Technology in Sudan: Challenges and Educational Gaps

Radiologic technology is a relatively new profession in Sudan, introduced in the early 21st century (Abdelrahman*et al.*, 2022). Despite several universities offering four-year bachelor’s degrees in this field, the quality of education remains suboptimal due to outdated pedagogical approaches and the limited involvement of educational experts. Most training follows the traditional “apron model”, where students learn by observing and then practicing directly on patients without prior simulation-based preparation. This method often leads to stress and reduced clinical confidence, especially in low-resource settings like Sudan, where access to modern diagnostic tools is limited (Akoob*et al.*, 2022). Sudan's fragile political environment and recurring conflicts compound these challenges, disrupting higher education and straining academic infrastructure (Suji*et al.*, 2024). Many institutions still use outdated equipment, lack digital imaging tools, and have minimal access to simulation laboratories. Moreover, collaboration between academic and clinical training centres is often weak, hindering practical skill development (Kawooya, 2012).

Advancing Radiologic Education through Simulation and Innovation

Simulation-based learning is one of the best ways to close the theory-clinical practice gap. From high-fidelity mannequins to affordable phantoms, healthcare education has embraced simulation tools globally, from which students may have a safe, repeatable, and feedback-rich training environment (Chau*et al.*, 2022). These approaches improve technical competencies and help to develop soft skills, including communication and decision-making. Simulation is not yet extensively used in Sudan.

An interesting, risk-free environment allows tools such as the "X-ray Clinic" interactive software to help teach anatomy, positioning, and imaging concepts (Gulati*et al.*, 2019). Simulation reduces patient risk and promotes ethical learning, particularly in underprivileged healthcare systems. Sudan must invest in simulation infrastructure, improve institutional co-operation, and get support from NGOs and foreign partners to modernise radiologic education. By doing this, Sudanese initiatives will be better prepared for real-world clinical settings and match global norms (Suji*et al.*, 2024; Akoob*et al.*, 2022). Improving educational results and healthcare delivery in Sudan depends on simulation-based training; it is no longer optional.

Transforming Radiologic Technology Education using Simulation

Simulation-based education (SBE) has become increasingly crucial in radiologic technology training. Its acceptance among health profession education has been driven by current students' growing digital literacy and educational technology developments (Sujar*et al.*, 2022). Simulations give students controlled, risk-free environments that quite closely reflect clinical environments. Using realistic, distraction-free experiences, they improve focus and clinical decision-making; reflective practice provides formative and summative assessment possibilities.

In radiography, conventional instruction sometimes pays excellent attention to technical skills while ignoring the essential human elements influencing patient care. Development of immersive simulation systems aims to close this difference. These systems combine optical trackers, commercial game engines, and spatial sound to replicate radiographic surroundings. Based on core radio-physics concepts, students can interact with virtual patients and control radiographic equipment (Sujar*et al.*, 2022). The ability to control anatomical views and perform tasks collaboratively enhances realism. Video recordings and self-assessment tools further support student learning, aligning with contemporary gamification methods in medical education.

A simulation-enhanced curriculum aims to achieve three primary learning objectives: first, improving patient interaction skills (both technical and non-technical); second, executing practical X-ray examinations in varied scenarios; and third, developing a precise understanding of anatomical projection for image acquisition. Virtual reality (VR) and 3D modelling allow students to visualise complex anatomical structures and create accurate mental models, making abstract concepts more accessible (Akoob*et al.*, 2022). As global health science programmes evolve, institutions increasingly adopt SBE to better prepare students for the demands of modern diagnostic imaging environments.

Implementation Strategies for Simulation-Based Learning

Implementing simulation-based programmes in developing nations such as Sudan requires a structured framework. The simulation programme in Sudan followed a five-step implementation model. After ethical approval, a team of educators and administrators assessed existing educational gaps and evaluated training quality for radiologic technologists. Their analysis confirmed the need for a more consistent and effective learning approach across institutions. Step one identified the need for reform. Step two involved crafting a clear implementation plan inspired by successful models from Egypt, Saudi Arabia, and the United Arab Emirates (UAE). This included defining core features, timelines, and integration strategies to ensure the programme's sustainability. Step three entailed stakeholder analysis, identifying 15 stakeholders categorised by their level of influence and interest, ranging from academic leaders to regional policy-makers. Step four addressed Sudan's socio-political environment, recognising the necessity of flexible, online education in times of national uncertainty.

Engaging a vast network of stakeholders was essential to protect the programme from future disruptions (Akoob*et al.*, 2022). Step five focused on designing targeted communication strategies for each stakeholder group, ensuring consistent information flow and alignment with programme goals. Instructor training formed a crucial part of the curriculum's success. Many students struggle to bridge the gap between classroom instruction and clinical practice. To resolve this, simulations were introduced to model imaging conditions in radiography, mammography, CT, ultrasound, and fluoroscopy modalities. Instructors could configure diverse scenarios, visualise simulated imaging parameters, and highlight potential errors in technique (Sujar*et al.*, 2022). A built-in library of over 200 preconfigured scenarios allowed for personalised instruction and improved training for both students and medical physicists involved in imaging quality assurance.

Student Engagement and Evidence from Case Studies

Active student engagement is fundamental to the success of simulation-based education. Simulations foster curiosity and critical thinking by safely allowing learners to handle equipment, address faults, and test techniques. Discussion-based sessions promote reflection, helping students identify learning gaps and reinforce clinical reasoning (Chau*et al.*, 2022). Instructors often use follow-ups, peer discussions, and pre-case submissions to adapt simulations to individual knowledge levels.

Programmes combine recorded tutorials, peer-led support meetings, and FAQs gathered over the semester to lower anxiety and inspire help-seeking activity. Beginner courses such as "How to Succeed in Your Radiography Assignments" seek to boost confidence and gently address shared student issues in a motivating environment.

One successful case study at Northumbria University shows the possibilities of interactive simulations in radiographic education. The university installed a real-time X-ray simulation and patient positioning system to augment conventional lectures and solve clinical placement shortages in 2021. Under a simulated radiography room, students ran a 3D avatar, learning about tube geometry, positioning techniques, and patient handling, all available via a web browser. Feedback following implementation showed overwhelmingly favourable results: 96% of students either agreed or remained neutral on the system's value to their learning. The simulation environment bridged the theory-practice gap, greatly improved understanding of imaging techniques, and enhanced learning. Inspired by these findings, related models are investigated for veterinary radiography and other specialised imaging domains (Gulati*et al.*, 2019).

Inspired by this success, colleges have started creating similar platforms, including for veterinary radiography, where sophisticated patient scenarios call for specific simulation tools. Combining technical accuracy, human-centred practice, and technology-enhanced instruction in simulation-based learning transforms radiologic education. These programmes significantly improve student preparedness using careful implementation, curriculum design, and faculty training, especially in areas with restricted access to clinical training. Practical results and case studies validate that simulation promotes better clinical competency, learning, and engagement. Adopting simulation will be essential as educational systems change to produce competent, flexible, confident radiologic technologists ready to meet worldwide healthcare needs.

Simulation-based training revolutionises radiologic technology education by providing immersive, interactive learning experiences that bridge the gap between theory and practice. As digital tools continue to evolve, integrating simulation into radiographic curricula can enhance educational equity, improve skill acquisition, and better prepare students for complex clinical environments, especially in resource-limited countries. The success stories from universities and innovations in VR platforms provide a compelling roadmap for broader adoption and future development.

Radiologic Technology Education in Sudan: A Focus on International Collaboration and Curriculum Innovation

Sudan hosts several institutions offering radiologic technology programmes, including the Sudan University of Science and Technology (the largest in student body), the National University of Sudan, Alzaiem Alazhari University, the National Ribat University, Elrazi University, the University of Medical Sciences and Technology, and Karary University. These universities contribute to training radiologic technologists and improving imaging services in the country. Efforts are ongoing to establish national imaging standards and protocols in collaboration with professional bodies.

A focus on continued and mid-career education aims to support radiologists and technologists. However, challenges remain, especially at institutions such as National Ribat University, where limited funding hinders the procurement of essential simulation equipment for labs, such as CT and physics labs.

Despite having appropriate classroom and laboratory infrastructure, many institutions lack the technical resources to deliver effective simulation-based education. Global partnerships are crucial to the enhancement of radiologic training in Sudan. International collaborations provide avenues for technological exchange, curriculum development, and expansion of simulation-based programmes. These partnerships help bridge training gaps in developing countries and promote equitable access to radiologic education for students from disadvantaged backgrounds (Akoob*et al.*, 2022). By means of simulation labs furnished with contemporary technologies, students can engage in safe radiologic practice and learning. Practical experience, using creative learning strategies, and building models that replicate real-life events take centre stage.

Under the direction of national bodies, institutions are urged to create frameworks for good practice, including licensure criteria, continuous professional development, standardisation, and quality assurance. Crucially, local projects are also motivated by young radiologic engineers. These projects propose workshops to support inclusive technology development, document informal learning environments, and match current content with developing technologies (Sujar*et al.*, 2022).

In simulation-based training, evaluation of student performance combines several approaches: observations, interviews, focus groups, and systematic questionnaires. Improving training plans depends much on student and instructor comments. Written questionnaires and semi-structured interviews gauge practical application and knowledge retention. Rubrics, peer and expert reviews, and self-assessment tools help to gauge performance. Simulations look like actual hospital environments to improve realism and decision-making abilities, including high-fidelity imaging tools and distractions (Gulati*et al.*, 2019). In simulation environments, feedback is fundamental for learning. It helps students develop their skills, offers insights into their performance, and points up areas that call for work. Direct (explicit and corrective) feedback systems can also direct indirect (promoting self-awareness). Automated feedback systems objectively assess learner behaviour using metrics including gaze tracking and task interaction (Wijewickrema*et al.*, 2017; Shah*et al.*, 2022). Regular peer reviews, curriculum revisions, and faculty development all contribute to the ongoing quality assurance that defines the sustainability of simulation training.

Specialised seminars and coaching could help faculty members to change their teaching strategies and adapt to evolving simulation technologies. Including reflective techniques and strong communication skills will help enhance faculty development (Mól*et al.*, 2017). By enhancing radiologic services in under-developed areas such as Darfur, simulation-based education is expected to revolutionise healthcare delivery in Sudan. Many Sudanese technologists receive poor instruction; most work without access to controlled learning materials or simulation tools. Poor imaging quality, higher radiation exposure hazards, and ineffective diagnosis methods follow from this. Turning now to simulation-based training presents a safe and reasonably priced substitute for conventional approaches.

Animated and narrated demonstrations improve learning (Sujar*et al.*, 2022), supporting student understanding and retention. Despite progress, scaling simulation training throughout all Sudanese institutions still presents a significant obstacle. Strategic leadership is needed from the Ministries of Health and Higher Education. Simulation models must be tailored to local socio-economic conditions, infrastructure, and educational needs if successful implementation in low- and middle-income countries (LMICs) is to take place (Maglio*et al.*, 2024). Customised training programmes, organised instructional rules, and localised materials are key to sustainability. Academies of regional health workers can advance continuity and connectivity. International co-operation is indispensable to guaranteeing fair distribution of qualified professionals and solving worldwide inequalities in healthcare training (Chau*et al.*, 2022; Van der Merwe*et al.*, 2017).

Training Ethical Considerations

Fundamental in nature, ethical training shapes the values, obligations, and behaviour of upcoming medical professionals. Ideally, starting early in the curriculum to shape students' attitudes and practices, medical ethics education raises awareness of human rights and responsibility in patient care (Sujar*et al.*, 2022; Mól*et al.*, 2017). Trainees should study many ethical theories and books, and practice self-assessment to prepare for moral conundrums. Grounded in social responsibility and human rights, these initiatives seek to improve healthcare professionals' ethical competency and autonomy (Unver*et al.*, 2019).

A crucial diagnostic tool, radiographic imaging calls for trained experts to guarantee patient safety and image quality. With the advent of digital imaging, radiography has become more complicated and requires exact control of system parameters, including collimation. Unneeded radiation exposure resulting from inadequate training or control emphasises the need for radiographers' experience and strong safety procedures (Sujar*et al.*, 2022). Automation and understaffed facilities help to raise the chances of misuse even more.

In education, cultural sensitivity is ever more critical. It entails designing settings that value and incorporate cultural diversity to remove educational obstacles. Research on simulation-based intercultural education has revealed that it might not notably improve students' self-perceived cultural sensitivity (Unver*et al.*, 2019; Maglio*et al.*, 2024). However, educational components, including simulated patient contacts addressing language restrictions, are valued (Wijewickrema*et al.*, 2017). Governments and legislators greatly influence the shape and control of simulation-based education. Expanding simulation technologies requires both national strategies and formal laws to guarantee safety, credential protection, and fair access.

Efforts in nations such as South Africa must address historically high X-ray exposures through control and improved radiography training (Akoob*et al.*, 2022; van der Merwe*et al.*, 2017). Using funding, technology development, and distance-based learning promotion, policy-makers can also support simulation training (Gulati*et al.*, 2019).

Educational initiatives benefit significantly from international and interdisciplinary collaboration. A Middle Eastern partnership involving universities from Cyprus, Sharjah, and Sudan exemplified successful co-operation in developing tailored training programmes. These included orientation courses, technical sessions, and simulation integration using culturally and institutionally relevant protocols. Communication and collaboration were key to developing shared goals, responsive support, and resource optimisation (Sujar*et al.*, 2022).

Community engagement and support are essential for successful simulation implementation. Simulations should reflect local healthcare needs and involve inter-professional collaboration. Hospitals can offer support through funding, infrastructure, and data that guide educational objectives (Walsh*et al.*, 2019). Partnerships with local organisations help align resources, facilities, and teaching staff with programme goals. To guarantee the quality of instruction, this entails setting up evaluation systems, outfitting radiology departments, and safeguarding portable technology (Abdelrahman*et al.*, 2022).

When developing simulation programmes, effective stakeholder engagement is essential. Since the technology is designed to aid their education, students pursuing radiologic technology should collaborate to create learning objectives. Locally relevant training is ensured through focus groups, surveys, and co-operative design sessions. To gain the support of institutional decision-makers, project teams must be transparent in their communication, explaining the programme's purpose and anticipated results (Chau*et al.*, 2022; Akoob*et al.*, 2022). Early intervention, co-operative planning, and supportive policies are necessary when incorporating ethical, culturally aware, and safety-focused principles into medical education through simulation technologies. Medical education is more efficient, equitable, and sensitive to global health issues when all parties involved, teachers, students, governments, and community partners, co-operate.

Challenges in Implementation

Modernising radiologic technologist (RT) education in Sudan necessitates investment in radiography simulator systems. However, alternative strategies must be adopted to bridge the gap due to high costs and limited availability. One proposed approach is the adaptation of current scenario-based training resources for use on standard computers, developing either equipment-free or virtual reality (VR) systems that are accessible to most university students (Suji*et al.*, 2024). While VR offers promise, its adoption is hindered by high initial costs and a steep learning curve, factors that led to a 90% failure rate in implementation among institutions. Consequently, equipment-free systems may provide a more feasible alternative in the short term.

Another suggestion involves compiling localised training scenarios adaptable to existing resources in Sudan (Akoob*et al.*, 2022). RT training in Sudan relies heavily on academic instruction and limited clinical exposure. As global healthcare evolves, so must the education of future radiographers, who will require enhanced skill sets to meet emerging challenges. Integrating interactive simulation technology into RT education could fill critical gaps left by conventional teaching methods, particularly the lack of real-time interaction. Drawing on constructivist educational theories and existing simulation models, researchers have developed a prototype simulation tool that combines graphical input, computation, and image output, which is slated for further development (Sujar*et al.*, 2022).

While some simulation initiatives exist in medical and nursing education in Sudan, radiology-specific programmes remain limited and underfunded. To address this, scholars propose using low-cost alternatives such as bentonite clay, cardboard-based models, and even 3D-printed mannequins, where funding allows. Motion capture technology and 2D projection simulators are also suggested due to their affordability and adaptability in local contexts. These solutions can provide practical training without costly infrastructure (Shah*et al.*, 2022).

Curriculum reform, however, is often met with resistance due to entrenched ideologies and institutional inertia. Change disrupts established roles and power structures within academia. Therefore, the change must be framed as targeted and constructive to implement reforms effectively, avoiding overreaction and systemic rejection. Gaining input from trusted educators and applying a comprehensive problem-solving approach can help define and refine reform objectives (Bank*et al.*, 2019; Chau*et al.*, 2022). Recommendations for improving RT training emphasise enhancing student exposure to simulation-based learning. This approach is particularly important for training in portable radiography and patient-centred care. Simulators offer a safe, low-stakes environment where students can practice, receive feedback, and build confidence before clinical placements. Training outcomes can be monitored using data analytics to tailor subsequent instruction and foster self-efficacy (Akoob*et al.*, 2022; Nguyen*et al.*, 2022).

The curriculum must also address critical safety and quality standards in medical imaging. Misapplication of radiographic procedures, especially in vulnerable populations such as children, can lead to serious health risks. Therefore, RTs must be proficient in theory and practical skills, including equipment use, patient positioning, and communication. However, many students in Sudan report inadequate exposure to these elements before clinical rotations. Traditional mechanical simulators are often low fidelity and labour-intensive to set up, while advanced computerised simulators, although more effective, are seldom used due to infrastructure limitations (Sujar*et al.*, 2022). Investing in technological advancement is essential. Developing countries such as Sudan face challenges, including limited Internet access and low computer literacy. Nonetheless, technology-enhanced learning has proven effective in improving knowledge retention and student engagement. Radiologic technology education must evolve to incorporate portable, accessible tools aligned with rapid technological progress. This evolution is critical to ensuring RTs are well-equipped to meet the demands of modern healthcare systems that require expertise in imaging physics, anatomy, and interdisciplinary collaboration (Akoob*et al.*, 2022).

CONCLUSIONS

Simulation-based education has long played a crucial role in aviation and healthcare by providing safe, controlled environments for learning complex skills. In Sudan, the ongoing war crisis has devastated healthcare infrastructure, disrupted medical education, and displaced thousands of students and professionals. As the nation looks towards rebuilding after the conflict, simulation-based training offers a strategic solution to restore and advance healthcare education, particularly in radiologic technology. With many clinical sites damaged or inaccessible and a shortage of imaging equipment, traditional hands-on training is no longer feasible. Simulation tools, especially those using augmented reality and visualisation, can fill this gap by offering immersive, interactive learning without physical equipment. These systems can be adapted to local needs and deployed in universities, refugee camps, and community centres. As Sudan rebuilds, investing in simulation-based education will be vital to training a new generation of healthcare workers, strengthening the health system, and supporting national recovery.

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BIOGRAPHY

Professor Dr Yousif Mohamed Yousif Abdallah is a renowned expert in Radiological Sciences with over 20 years of experience across leading academic institutions. Currently at Majmaah University, Saudi Arabia, he holds a PhD and two MSc degrees in radiation therapy and nuclear medicine. He has authored 93 research papers, 8 books, and 6 book chapters, and holds 16 medical device patents from the UK, India, and Canada. Professor Abdallah is celebrated globally for his innovations in medical imaging, radiation safety, and his dedication to mentoring future radiology professionals.

