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VIRTUAL SIMULATION FOR RADIATION PROTECTION EDUCATION AMONG UNDERGRADUATE MEDICAL RADIOLOGY AND IMAGING TECHNOLOGY STUDENTS IN INDIA: EVIDENCE, CHALLENGES, AND FUTURE DIRECTIONS

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Abstract

Background: Safe use of ionizing radiation is a core learning outcome for undergraduate Medical Radiology and Imaging Technology (MRIT) students. Their preparation must extend beyond knowledge of radiation physics to the practical application of justification, optimization, patient protection and occupational safety. Lectures and supervised clinical teaching remain indispensable, although students may have limited opportunities to rehearse uncommon or potentially hazardous situations repeatedly. Digital simulation can provide a controlled setting in which learners make safety decisions, observe modelled consequences and receive feedback without creating additional exposure for patients or staff.

Objective: This review considers how virtual simulation might be used to teach radiation protection, examines relevant findings from radiography and healthcare education, and explores its feasibility within Indian BSc MRIT programmes.

Review approach: A critical narrative approach is used to discuss selected publications on virtual reality, simulation-based imaging education and radiation-safety teaching. This is not a completed systematic review. A reproducible search and transparent study-selection process would be necessary before claiming comprehensive coverage of the literature.

Discussion: Potential learning activities include practising time-distance-shielding decisions, understanding scatter, selecting collimation and exposure factors, and recognizing opportunities to optimize dose. Published studies report encouraging learner responses and gains in some radiographic skills. Nevertheless, direct evidence of sustained improvements in radiation-protection behaviour, retention or clinical outcomes among Indian BSc MRIT students is not yet established. Cost, access to suitable devices, faculty preparation and curriculum alignment will influence implementation.

Conclusion: Virtual simulation is best considered an additional teaching method alongside classroom instruction, physical demonstrations and supervised clinical practice. Indian programmes should define the competencies to be taught, validate the scenarios and evaluate objective performance, retention, clinical transfer, accessibility and cost before wider adoption.

Keywords: virtual simulation; virtual reality; radiation protection; radiation safety; radiography education; BSc MRIT; medical imaging; India.

Introduction

Diagnostic imaging contributes to screening, diagnosis, treatment planning and follow-up. Modalities such as projection radiography, computed tomography (CT), fluoroscopy and mammography use ionizing radiation; their safe application therefore depends on justification of each examination and optimization of exposure. Students in undergraduate MRIT programmes must learn the scientific basis of radiation risks and demonstrate that they can apply protective measures during routine and less familiar clinical tasks.

Lectures, demonstrations, laboratory sessions and supervised placements provide the foundation for this learning. Clinical exposure, however, is not uniform: case mix, workload, equipment availability and service priorities determine which situations a student encounters. Repeated rehearsal of uncommon events or unsafe choices may be difficult to arrange in a functioning department, where teaching must never create unnecessary exposure.

Digital simulation offers a way to present repeatable cases in which learners choose an action, receive feedback and attempt the task again. Its educational value is determined less by the novelty of the technology than by the quality of the scenario, the accuracy of its feedback and the relevance of the assessment. Shetty et al. described favourable results for several radiology-learning outcomes, while emphasizing variation among the studies they reviewed [40]. Those broad findings should not be taken as direct proof that simulation improves radiation-safety practice.

The present review examines the possible contribution of virtual simulation to radiation-protection teaching for Indian BSc MRIT students. It distinguishes studies that directly address radiation-safety education from research on related competencies, such as positioning, image evaluation and CT workflow.

The educational objective is to move learners from knowing a safety rule to applying it appropriately. A student may correctly state that increasing distance reduces exposure yet fail to select a suitable location during mobile imaging. Similarly, knowledge of collimation does not necessarily translate into choosing a field that excludes unnecessary anatomy while retaining the region required for diagnosis. Teaching should therefore assess recognition, decision-making and the ability to explain the rationale for a chosen action.

Simulation may be particularly useful when a scenario is infrequent, difficult to reproduce safely or requires several attempts before a learner is ready for supervised practice. In a virtual case, an incorrect decision can be followed by an explanation and another attempt without exposing a patient. The modelled consequence must, however, be scientifically credible. The relevant questions are which competencies improve, whether the gains persist, whether they transfer to clinical work and whether the approach is feasible for the institution.

2. Review objective and approach

This review aims to examine the educational role of virtual simulation in radiation protection, appraise the relevance and limitations of selected evidence, consider practical issues affecting Indian programmes and outline a framework for implementation. The discussion is guided by five questions: which simulation formats may be useful; which radiation-safety competencies could be rehearsed; what findings have been reported; what weaknesses limit interpretation; and how could programmes introduce and evaluate this teaching approach?

The article is a critical narrative review rather than a completed systematic review. The reference set was assembled for this project and selected accessible papers were checked to clarify their designs and reported findings. A systematic review would require a documented search strategy, explicit eligibility criteria, duplicate screening, a record of exclusions and appraisal methods suited to each study design. PRISMA 2020 provides reporting guidance for such a review [18]. RoB 2 is designed for randomized trials, while the Joanna Briggs Institute provides appraisal checklists for other designs [19,21]. No PRISMA study counts or study-level risk-of-bias judgements are claimed in this manuscript.

A narrative synthesis is appropriate for the present discussion because the selected publications examine different technologies, populations, teaching tasks and endpoints. Rather than combine unlike outcomes into a pooled estimate, the review considers what each type of result can reasonably support. Study design, participant numbers where available, the match between intervention and outcome, and the relevance of the endpoint to radiation safety are therefore considered. Satisfaction and confidence are informative about acceptability, but they cannot replace demonstrated competence.

The discussion draws on primary research involving virtual radiography and CT education, the study of virtual simulation for radiation-protection teaching, a systematic review of VR in radiology education and publications addressing educational technology and review methodology. Because the material was not identified through a fully reproducible search for this manuscript, it should be regarded as a selected evidence base rather than an exhaustive inventory of relevant research.

3. Radiation protection education in undergraduate MRIT programmes

Radiation-protection education should prepare students to make safe decisions in practice, not simply reproduce definitions in an examination. The curriculum needs to cover radiation quantities and units, biological effects, justification and optimization, occupational monitoring, protective equipment, patient-dose awareness, quality assurance and safe departmental procedures.

Time, distance and shielding are practical foundations of occupational protection. Exposure can generally be reduced by limiting unnecessary time near a source, increasing distance when circumstances permit and making proper use of barriers. The protection achieved in a real room is also influenced by beam direction, patient size, equipment arrangement and the distribution of scattered radiation. Teaching should consequently use examples that require students to apply the principles to a particular geometry and task.

For patients, important considerations include restricting the irradiated field to the required anatomy, choosing suitable exposure settings, understanding the causes of repeat examinations and interpreting dose-related indicators. CT teaching should address scan coverage, the number and timing of acquisitions and the relationship between technical settings, image quality and dose. Optimization must not be misinterpreted as reducing exposure at the expense of diagnostic information or withholding a justified examination.

In India, teaching materials should be consistent with the programme curriculum, institutional standard operating procedures and relevant AERB requirements. The framework discussed in this article is intended to support existing radiation-safety teaching and clinical supervision, not to replace them.

A useful curriculum can group learning outcomes into three connected areas: scientific understanding, applied decisions and professional conduct. Scientific understanding covers radiation quantities, biological effects and factors that influence exposure. Applied decisions include field-size selection, avoiding unnecessary projections or CT acquisitions, and following local procedures for patient identification and pregnancy-related checks. Professional conduct includes clear communication, checking room readiness, complying with personal monitoring requirements, reporting safety concerns and seeking help when a situation falls outside the learner's competence.

The required competencies also vary by modality. In general radiography, learners should connect positioning, collimation and exposure selection with image quality and repeat rates. In CT, they should understand what CTDIvol and dose-length product describe, how scan length and additional phases affect displayed dose indices, and why these indices are not direct measurements of an individual patient's organ dose. Fluoroscopy requires attention to staff location, protective curtains and barriers, scatter and behaviours that avoid unnecessary screening. Mobile imaging adds the need to manage room access, protect bystanders and coordinate with ward personnel.

4. Virtual simulation: concepts and formats

The term virtual simulation covers several forms of computer-mediated practice. A desktop programme may present interactive cases, equipment interfaces or three-dimensional scenes on a conventional monitor. Immersive virtual reality generally uses a head-mounted display and motion-tracked controls to create a sense of presence in a computer-generated room. Augmented and mixed-reality systems place digital content within the user's view of the physical environment. These formats differ in immersion, interaction, accessibility and cost [4-8].

A desktop case may be entirely adequate when the learning task concerns selection of a scan range, collimation or an exposure option. A spatially immersive environment may be more helpful when learners need to understand where to stand in relation to the patient, X-ray tube, detector and protective barrier. Neither format fully recreates hands-on positioning, patient movement, communication or the tactile response of clinical equipment. In a randomized study of 30 radiography students, some outcomes after head-mounted VR were similar to those after physical practice, whereas performance was weaker for tasks involving palpation and patient interaction [27].

The platform should therefore be chosen only after the intended competency has been specified. Learning objectives, affordability, accessibility, technical support and evidence of educational benefit are more important selection criteria than the level of immersion alone.

The differences between simulation formats have practical consequences. A non-immersive case may use a room plan, a sequence of choices and explanatory feedback. A three-dimensional model can add movement around equipment and make spatial relationships easier to explore. Head-mounted systems may increase the sense of presence, but they also require suitable hardware, a safe operating area, maintenance and support; some users may experience discomfort. Haptic systems add selected tactile cues, although these cues cannot reproduce every physical feature of equipment or patient contact.

Fidelity should be considered in relation to the task being taught. A screen-based interface can be sufficient for interpreting a dose display or comparing scan coverage. Spatial rehearsal may be valuable when choosing a

position in a fluoroscopy room or identifying the relationship between the patient and scatter source. Communication and patient preparation require dialogue and interpersonal interaction, so a virtual case may need to be paired with role-play. Detailed graphics that do not contribute to the learning outcome add complexity without necessarily improving learning. Clear objectives, meaningful choices, accurate feedback and a guided debrief are central design features.

5. Potential educational applications in radiation protection

5.1. Time, distance and shielding: A simulated room can let students choose a position, identify protective barriers and compare modelled exposure indicators under different conditions. Feedback should explain the principle behind each decision and clearly label simulated outputs.

5.2. Scatter radiation and occupational safety: A virtual interventional suite could show the patient, X-ray tube, detector, staff locations and protective curtains. Learners could identify safer positions and compare choices. The software should communicate that real scatter fields vary with geometry, patient characteristics and procedural factors.

5.3. Collimation and repeat examinations: Students could choose a field size for an examination and receive feedback about unnecessary irradiation or the risk of excluding required anatomy. Scenarios may ask learners to identify causes of avoidable repeat imaging, including positioning and exposure errors, while emphasizing that clinically necessary repeat imaging must not be discouraged.

5.4. Exposure selection and image quality: Interactive cases can show how exposure choices influence image appearance and dose-related indicators. Simulated relationships must be based on validated models and should not be presented as actual patient dose measurements.

5.5. CT dose awareness: Scenarios could involve scan length, unnecessary phases, repeat acquisitions and interpretation of CTDIvol and dose-length product. Learners should understand that these indicators are not interchangeable with patient-specific absorbed dose. Simulations must not encourage unsupervised protocol modification on clinical scanners.

5.6. Fluoroscopy and interventional procedures: Learners can rehearse room positioning, use of protective equipment and identification of scatter sources. This is a particularly relevant use case because real-time procedural environments may be difficult to reproduce consistently for every student.

5.7. Assessment: Simulation can provide formative feedback and structured scoring for hazard recognition, decision-making and adherence to safety principles. These assessments should complement written tests, objective structured clinical examinations and direct observation in clinical placements.

Scenario design should include both routine and challenging situations. Routine cases establish correct habits, while progressively more complex cases require learners to prioritise safety when the room is crowded, the patient cannot easily cooperate, the examination is urgent or equipment layout constrains movement. The scenario should not reward a single memorised action without context. For example, a distance scenario should ask the learner to identify a safe location while maintaining communication and avoiding obstruction of care. Feedback should explain the principle and identify when institutional policy or a supervising radiographer must guide the final decision.

Debriefing is a key educational component rather than an optional discussion after the technology. A structured debrief can ask what the student noticed, which risks were considered, why a particular action was chosen, what the simulated feedback showed and how the same principle would be applied in a real department. Instructors should distinguish an error in radiation-protection reasoning from a software-navigation error. A learner who selects the wrong virtual control may need interface orientation, whereas a learner who knowingly chooses an unsafe position needs targeted conceptual feedback. This distinction improves fairness and helps faculty decide whether additional practice is needed.

6. Critical review of published evidence

Among the selected publications, Rainford et al. [31] are the most directly relevant to radiation-protection teaching. Their study explored student views of three-dimensional VR training in a simulated interventional radiology setting. The study enrolled 35 radiography students and 100 medical students; completed responses were obtained from 27 and 49 students, respectively. Of the respondents, 80% said they enjoyed the experience and 73% reported greater confidence across relevant learning outcomes. These results suggest that the activity was acceptable to many participants and may help introduce safety concepts. Because the outcomes were self-reported, however, they do not demonstrate better observed practice, sustained retention or a reduction in occupational exposure [31].

O'Connor and Rainford [30] examined clinical assessment results from two successive student cohorts: 93 students taught before VR was introduced and 98 students who received seven hours of VR practice. The later cohort achieved higher scores on 20 of 22 criteria, with statistically significant differences in selected areas

such as positioning, exposure-factor choice and image assessment. This is relevant evidence that practice in a virtual environment may support some aspects of subsequent radiographic performance. The retrospective cohort design cannot exclude differences in teaching, assessment or student characteristics between years, and the outcomes were not a dedicated test of radiation-protection behaviour [30].

Kato et al. [27] compared head-mounted VR coaching with practice using physical equipment in a randomized group of 30 first-year students. Results were not uniformly in favour of VR: some assessed skills were comparable, but learners in the VR group performed less well on tasks involving palpation and interaction with a patient. This finding is important because it identifies competencies that may not be adequately reproduced by a virtual interface. It supports combining digital rehearsal with hands-on teaching and assessment rather than treating the two approaches as interchangeable [27].

Other studies provide evidence about related imaging competencies. Bridge et al. [23] evaluated an immersive training environment; Ahlqvist et al. [22] investigated simulation-based approaches to image-quality assessment; and Gunn et al. [24,25] examined virtual practice for undergraduate imaging skills and CT learning. O'Connor et al. [15] also reported student experiences of three-dimensional radiography simulation. These studies help establish the educational potential of simulation for imaging education, but their outcomes—such as positioning, image evaluation or CT workflow—should not be relabelled as radiation-safety outcomes.

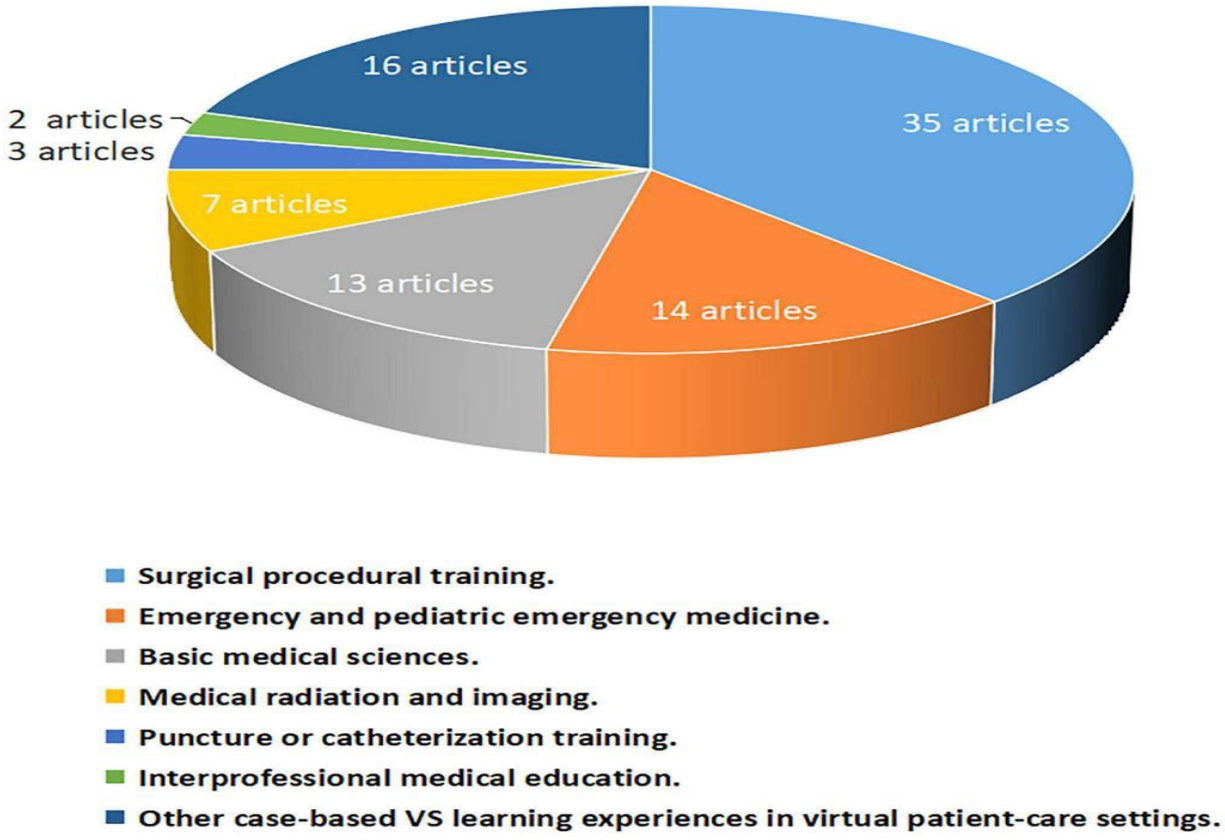
Shetty et al. [40] synthesized 17 studies in a systematic review of VR in radiology education. The review described favourable results for several radiographic and radiological skills, but also highlighted variation in study designs and outcome measures. Its conclusions provide a useful overview of the wider educational field; they do not provide a specific effect estimate for radiation-protection training. Publications on VR in higher education and medical education offer further conceptual context [1-3,6,10], although this broader material is indirect when the outcome of interest is safe behaviour around ionizing radiation.

Table 1. Critical comparison of selected studies

Study	Design / population	Key contribution / findings	Relevance and limitation
Rainford et al. (2023) [31]	Perception study; 35 radiography and 100 medical students; responses from 27 and 49, respectively.	80% enjoyed VR; 73% felt it enhanced confidence across relevant outcomes.	Direct radiation-protection topic; outcomes are perceptions/confidence, not objective long-term competence or dose reduction.
O'Connor & Rainford (2023) [30]	Retrospective cohort; control n=93, VR n=98; seven hours of VR practice in the latter cohort.	VR cohort performed better on 20/22 clinical assessment criteria; selected differences were statistically significant.	Supports possible clinical transfer for radiography skills; not a dedicated radiation-safety outcome study and historical cohort confounding is possible.
Kato et al. (2022) [27]	Randomized study; 30 first-year radiography students, 15 per group.	Some skills were comparable; VR group performed worse in tasks involving palpation and patient interaction.	Shows limits of VR and supports combining simulation with physical practice; not radiation-protection-specific.
Bridge et al. (2014) [23]	Development/evaluation of immersive medical imaging environment; student practical assessment.	Reported improvement on selected equipment/positioning assessment outcomes compared with traditional training.	Supports feasibility of simulated imaging practice; limited direct relevance to radiation-safety competence.
Ahlqvist et al. (2013) [22]	Randomized study of simulation-based training in radiology technology students.	Evaluated image-quality assessment skill using simulation-based approaches.	Controlled educational evidence, but image-quality skill is not equivalent to radiation protection.
Gunn et al. (2018, 2021) [24,25]	Undergraduate medical imaging / radiation	Examined VR for technical skills and CT	Supports educational application; dose

	therapy simulation studies.	simulation learning.	optimization and safety behaviour require direct measurement.
Shetty et al. (2024) [40]	Systematic review; 17 studies included.	Reported benefits for selected radiology skills and positive student feedback; noted study heterogeneity.	Broad contextual evidence, not a radiation-protection-only effect estimate.

Taken together, the selected literature indicates that virtual simulation is educationally plausible, is often received positively by learners and may improve selected technical skills. The evidence is less conclusive for transfer to radiation-safety behaviour. On the basis of these studies, it would be premature to claim that VR reduces staff exposure, lowers patient dose or produces durable safety improvements among Indian BSc MRIT students.



7. Relevance to Indian BSc MRIT programmes

Indian MRIT programmes operate in settings that differ in student intake, staffing, digital infrastructure, clinical workload and access to simulation facilities. A shared virtual scenario can offer each learner a comparable opportunity to practise a particular safety decision, even when their clinical placements expose them to different cases. It can also allow students to repeat a task and receive consistent feedback before attempting it under supervision.

A gradual introduction is likely to be more practical than beginning with a costly immersive installation. Initial activities could use interactive computer cases, annotated room layouts and facilitated scenario discussions. Head-mounted VR can be considered later where spatial navigation is an important learning outcome and where the institution can provide maintenance, technical assistance and trained facilitators.

Radiography educators and personnel responsible for radiation safety should review the scenarios before they are used with students. The material should be mapped to course outcomes and revised when relevant guidance or local procedures change. Any displayed dose or scatter values must be identified as simulated outputs, with the assumptions behind them made clear. Evidence of effectiveness and affordability should be generated in Indian programmes rather than presumed from overseas studies.

Local implementation decisions should reflect the number of learners, available teaching time, placement capacity and the resources that can be maintained over several academic years. A desktop activity accessible to an entire class may reach more students than a small number of headsets. On the other hand, a shared immersive facility may be worthwhile if spatial rehearsal is a defined need and the equipment can serve more than one course. Institutions should assess how many students can complete the planned learning activity, not simply whether the technology is available.

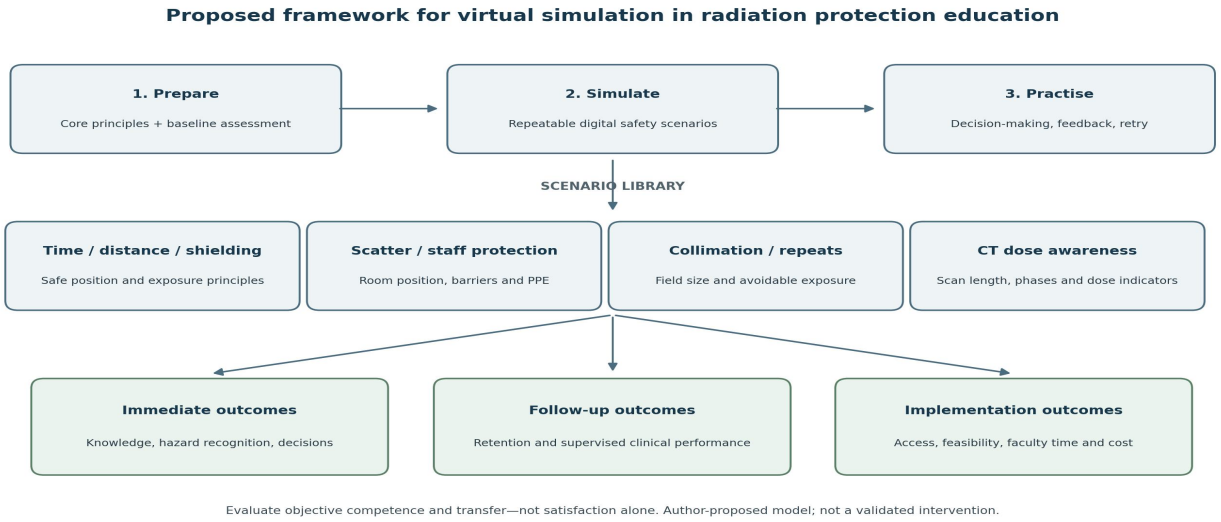
Scenarios should resemble the equipment and working arrangements students are likely to encounter, including fixed radiography rooms, mobile examinations, CT and fluoroscopy where these services are available. Terminology, room layouts and decision points should be consistent with local practice and institutional policy. English-language teaching can be supplemented with concise local-language explanations or a glossary where this improves comprehension. Alternative participation routes should be available for learners who cannot comfortably use a headset because of motion sensitivity, visual limitations or mobility-related needs.

Table 2. Proposed outcome framework for Indian BSc MRIT programmes

Domain	Suggested measure	Timing	Purpose
Knowledge	Pre/post test with content-reviewed questions	Before and immediately after	Measure knowledge gain
Safety decisions	Scenario rubric for hazard recognition and protective action	Immediately after training	Assess applied decision-making
Practical competence	Structured practical / OSCE-style assessment	After training	Assess demonstrated performance
Retention	Equivalent follow-up assessment	Predefined delay, e.g. 8–12 weeks	Assess persistence of learning
Clinical transfer	Standardized supervisor checklist during placement	During supervised practice	Assess application outside simulation
Feasibility	Access, completion, technical failures, staff time and cost	During implementation	Assess suitability and sustainability

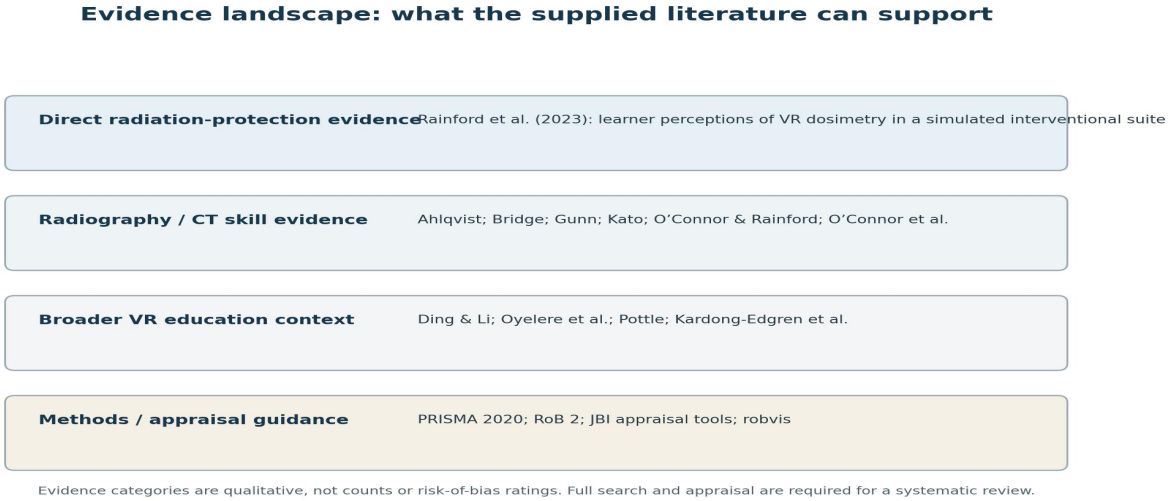
8. Proposed implementation framework

Stage 1—Needs assessment: identify curricular competencies and common errors observed during supervised practice. Stage 2—Scenario design: develop cases on time, distance and shielding; scatter and staff position; collimation; repeat imaging; exposure selection; and CT dose awareness. Stage 3—Platform selection: choose desktop, 3D or immersive VR according to learning goals, cost, accessibility and technical support. Stage 4—Guided practice: provide a short preparatory lesson, allow independent decisions, give explanatory feedback and permit repeat attempts. Stage 5—Assessment: use pre/post knowledge tests and a structured practical rubric. Stage 6—Clinical integration: discuss scenarios during supervised clinical training and assess transfer using a standardized checklist. Stage 7—Evaluation: measure participation, technical failures, faculty workload, learner accessibility and cost per student.



Author-developed conceptual framework. It is proposed for future evaluation and is not a validated intervention.

Figure 1. Proposed conceptual framework



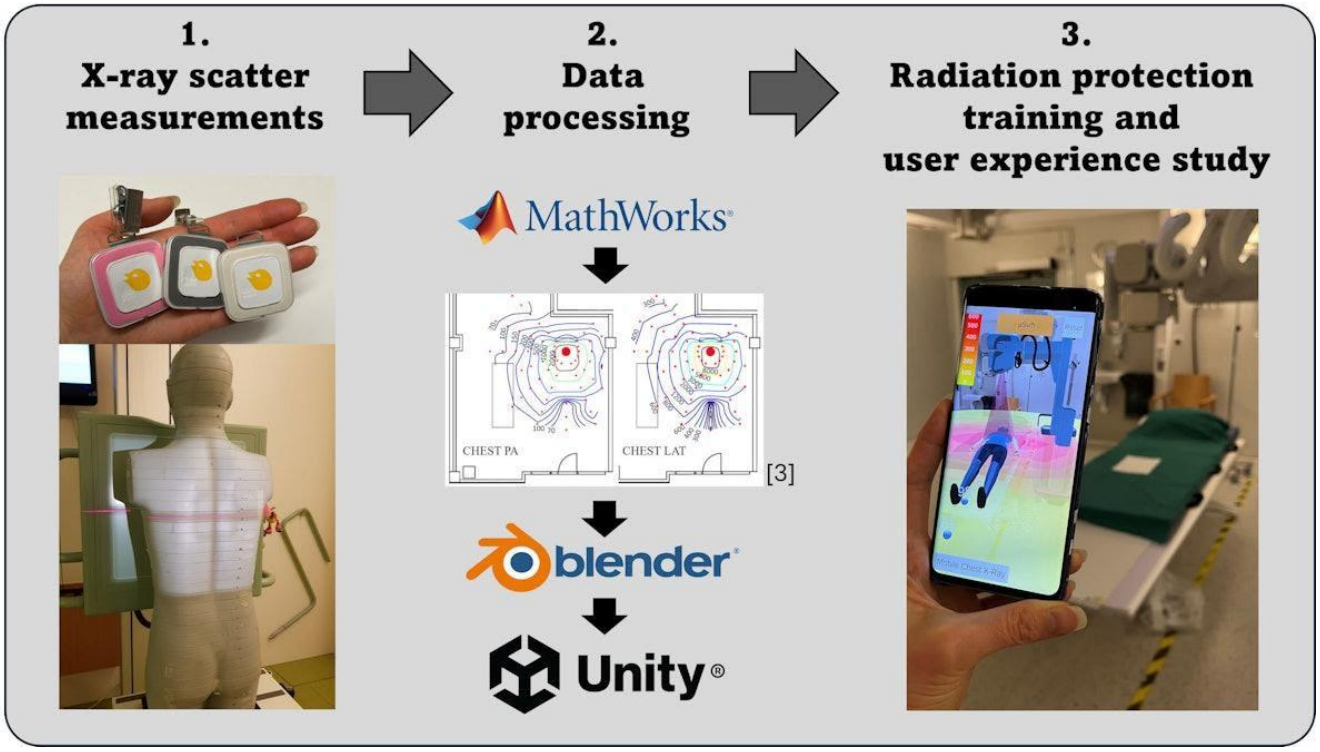
Qualitative evidence map separating direct radiation-protection research from adjacent radiography/CT studies, broader VR literature and methodological guidance. This figure does not represent study counts or risk-of-bias judgments.

Figure 2. Evidence landscape

This is an author-proposed framework, not a validated intervention. It should be tested in a pilot study before routine implementation. Figure 1 summarizes the framework; Figure 2 separates the direct radiation-protection evidence from broader radiography and general VR literature.

A practical pilot can be organised over one teaching block. Before the intervention, students complete a knowledge test and a short structured scenario assessment to establish baseline performance. They then receive a brief orientation to the controls, followed by guided practice and independent scenarios. The instructor uses a standard debriefing guide and records the types of errors observed. Immediately after the session, students complete the same or a parallel knowledge test and a performance assessment. A delayed assessment several weeks later can test retention, while a supervised clinical observation can examine whether the student applies the same principles in practice. Where feasible, an assessor who is unaware of group allocation should score the performance assessment.

The comparison group should receive an educationally credible alternative, such as a conventional case-based session or instructor-led demonstration, rather than no teaching. Both groups should have equivalent learning objectives, teaching time and access to core content. If the purpose is to test the added value of immersion, the comparison should ideally use the same scenarios on a desktop interface; if the purpose is to test simulation against conventional teaching, the comparator should reflect current usual practice. Clear definition of the comparator prevents a study from attributing differences to VR when they may be due to additional practice time or more frequent feedback.



9. Challenges and limitations

The financial assessment should include more than the initial purchase price. Relevant costs may include hardware, software licences, scenario development, technical support, cleaning, replacement, faculty training and periodic content updates. A low-cost platform may become expensive if it requires recurring subscriptions or does not permit local editing. Before procurement, departments should define the competencies to be taught and compare the available options against those requirements. For a pilot, interactive slides, simple three-dimensional room plans or existing institutional digital resources may be sufficient.

Technical usability and learner factors also influence the quality of the experience. Some students may experience dizziness, visual fatigue or discomfort with head-mounted displays, while others may need additional orientation to the controls. If navigation is difficult, the interface can distract from the safety decision being assessed. A simplified virtual environment may also create unwarranted confidence if it omits patient movement, communication demands, equipment variation or time pressure. For these reasons, simulation should be followed by supervised clinical practice and should not be the sole basis for confirming competence in tasks requiring physical or interpersonal judgement.

10. Research priorities

Future studies should establish whether simulation produces measurable improvements in radiation-protection decisions, rather than relying mainly on learner satisfaction. Comparisons across Indian institutions should include programmes with different levels of digital infrastructure and should use equivalent learning objectives and assessment conditions. Researchers should also separate the effects of the software from additional practice time, instructor attention and feedback.

A second priority is the quality of measurement. Researchers should develop or adapt transparent scoring rubrics for hazard recognition, time-distance-shielding decisions, staff positioning, collimation, repeat avoidance, interpretation of CT dose indices and appropriate escalation to a supervisor. Where performance is rated by observers, inter-rater agreement should be reported. Tests should assess application of knowledge rather than recall alone. Delayed assessments and structured workplace observations are needed to examine

retention and transfer. Dosimetry outcomes may be considered in later studies, but they require ethical oversight and appropriate consideration of equipment, workload and case mix.

11. Limitations of this review

This article is a narrative discussion of selected references, not the product of a comprehensive, reproducible search with duplicate screening and documented study selection. Relevant publications may have been missed, including work in regional journals or databases not searched during preparation. The evidence set combines conceptual papers, general VR literature, perception surveys and studies of practical imaging skills. Findings from positioning or image-quality training inform the use of simulation as a teaching method but remain indirect for radiation-protection competence. A future systematic review would require a defined search strategy, eligibility criteria, transparent screening and appraisal methods appropriate to each study design.

12. Conclusion

Virtual simulation could strengthen radiation-protection teaching for undergraduate BSc MRIT students by allowing repeated practice in hazard recognition and protective decision-making without generating additional exposure during the learning activity. The most directly relevant study in the selected literature describes favourable student perceptions of VR-based radiation-safety teaching. Other radiography studies indicate that simulation may assist the development of selected technical skills and preparation for clinical work.

These findings require cautious interpretation. Positive feedback, increased confidence or improved positioning scores do not in themselves demonstrate safer behaviour, durable learning or lower patient and occupational dose. A blended approach—combining theoretical instruction, scientifically reviewed scenarios, physical practice and supervised clinical assessment—is therefore the most appropriate current recommendation. Indian programmes should evaluate objective competence, retention, clinical transfer, accessibility and cost before advocating wider implementation.

Virtual simulation is best understood as a structured adjunct to radiation-protection education, not a replacement for lectures, physical demonstrations, supervised clinical placement or competency assessment. Its strongest potential lies in repeatable rehearsal of decisions that are difficult to practise consistently in clinical settings, including staff positioning, time-distance-shielding choices, collimation, avoidance of unnecessary imaging and interpretation of dose-related indicators. Current literature supports feasibility, learner acceptability and improvements in selected radiography skills, but evidence of sustained improvements in radiation-safety behaviour among Indian undergraduate MRIT students remains limited.

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