

SIMULATION AND VIDEO-BASED INSTRUCTIONAL DESIGN FOR ENHANCING CONCEPTUAL AND PRACTICAL LEARNING IN RADIATION-MATTER INTERACTION COURSES IN MEDICAL UNIVERSITIES

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Abstract.

The increasing reliance on radiation-based diagnostic and therapeutic technologies necessitates innovative pedagogical approaches in medical physics education. Radiation–matter interaction constitutes a foundational yet conceptually demanding subject for medical students, often associated with limited visualization and insufficient practical engagement when taught through traditional methods. This study proposes and empirically evaluates a simulation- and video-based instructional design for theoretical and practical training in radiation–matter interaction courses at medical universities. A quasi-experimental research design was implemented across multiple institutions, involving control and experimental groups. The experimental groups engaged with electronic simulators, virtual laboratories, and clinically oriented video demonstrations, while control groups received conventional lecture-based instruction. Quantitative analyses revealed statistically significant improvements in conceptual understanding, practical skill mastery, learning effectiveness, and student motivation among learners exposed to the simulation-based approach ($p \leq 0.05$). The findings demonstrate that technology-enhanced instructional design not only improves learning outcomes but also bridges the gap between abstract radiation physics concepts and their clinical applications. The proposed framework offers a scalable model for integrating simulation-based learning into medical physics curricula aligned with international standards.

Keywords:

Simulation-based learning; radiation–matter interaction; medical physics education; video-based instruction; virtual laboratories; technology-enhanced learning

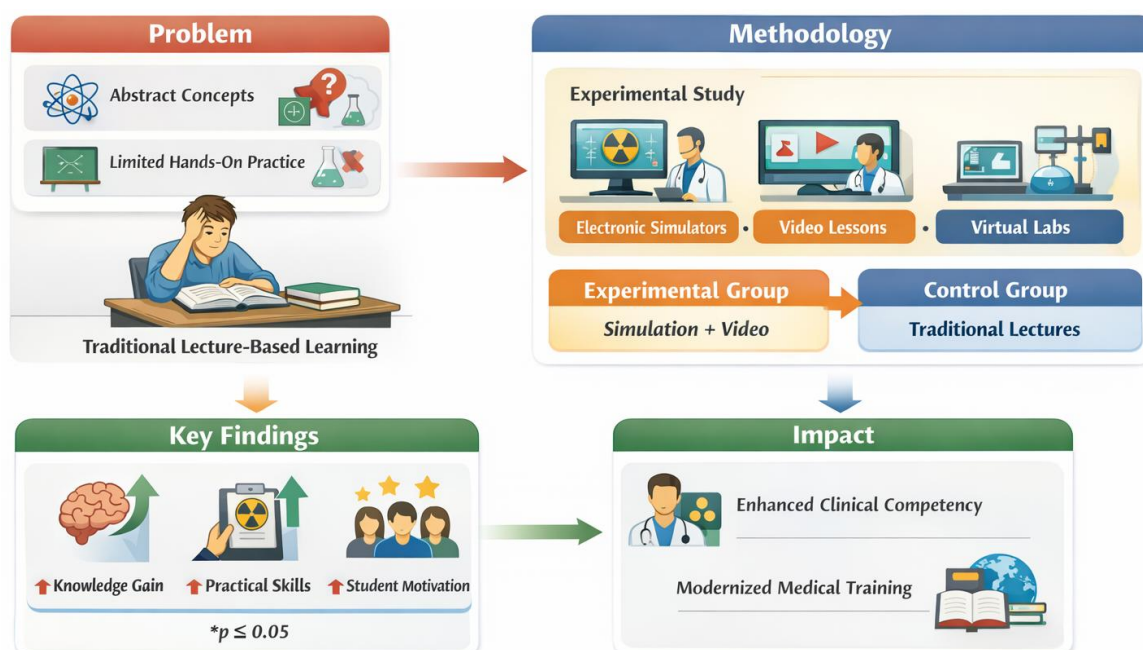
Introduction.

Radiation technologies are central to modern healthcare, underpinning diagnostic imaging, radiation therapy, and nuclear medicine. Consequently, medical education must ensure that students develop robust conceptual and practical competencies related to radiation–matter interaction processes. These competencies are essential for clinical decision-making, patient safety, and compliance with radiation protection standards. Despite its importance, radiation–matter interaction remains one of the most challenging subjects within medical physics curricula. The abstract nature of radiation processes, reliance on probabilistic interaction models, and limited access to experimental demonstrations contribute to cognitive barriers for learners. Traditional lecture-based instruction often fails to provide sufficient experiential learning opportunities, resulting in fragmented understanding and reduced motivation.

Advances in educational technology, particularly electronic simulators and video-based learning environments, offer promising solutions to these challenges. Simulation-based learning enables learners to visualize, manipulate, and analyze radiation interactions within virtual environments, thereby fostering deeper conceptual engagement. This study investigates the effectiveness of integrating simulation- and video-based instructional design into radiation–matter interaction courses at medical universities.

Theoretical Framework

This research is grounded in cognitive theory of multimedia learning and constructivist learning principles. According to Mayer's multimedia learning theory, learners achieve deeper understanding when information is presented through coordinated visual and verbal channels rather than text alone. Electronic simulators and video demonstrations align with this framework by reducing extraneous cognitive load and supporting germane processing. Constructivist learning theory further emphasizes active learner engagement through exploration, experimentation, and reflection. Simulation-based environments allow students to construct knowledge by interacting with virtual radiation models, testing hypotheses, and receiving immediate feedback. These theoretical perspectives collectively justify the integration of electronic simulators and video programs in teaching radiation-matter interaction.



Research Design and Methods.

A quasi-experimental design was employed, consisting of diagnostic, instructional, and evaluative phases. The study was conducted over two academic years across several medical universities. The sample comprised over 300 undergraduate medical students enrolled in radiation-related physics courses. Participants were

assigned to experimental and control groups with comparable baseline characteristics.

The experimental groups engaged with:

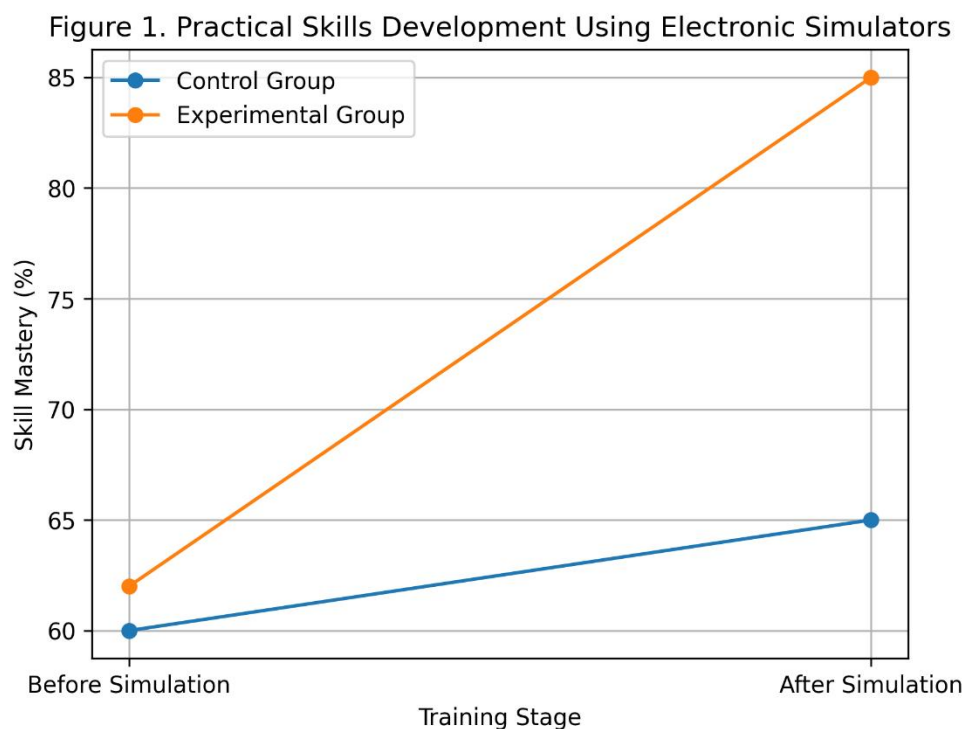
- a) electronic radiation simulators modeling photon, electron, and neutron interactions;
- b) virtual laboratories for dose calculation and shielding analysis;
- c) video-based clinical case demonstrations;
- d) interactive assessment tools with formative feedback.

Control groups followed traditional lecture-based and limited laboratory instruction. Learning outcomes were assessed through pre-tests, post-tests, expert evaluations, and student surveys. Statistical significance was evaluated using Student's *t*-test and effect size analysis ($p \leq 0.05$).

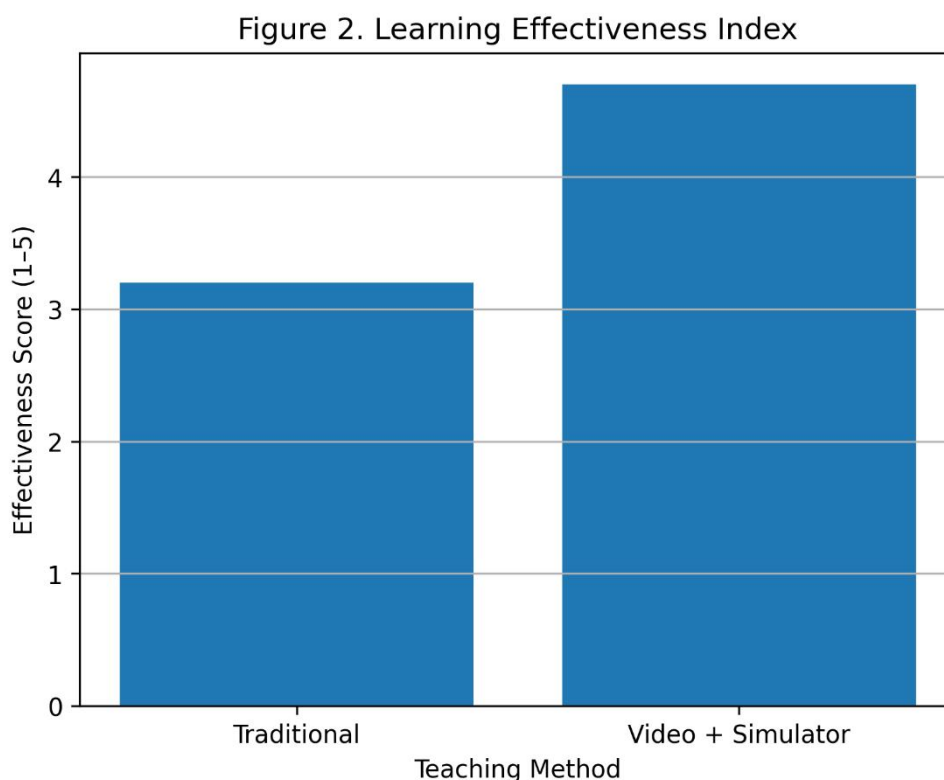
Results

The experimental groups demonstrated statistically significant improvements across all measured indicators. Conceptual understanding scores increased by more than 30%, while practical skill mastery improved by over 20% relative to control groups. Learning effectiveness indices and motivation scores

also showed substantial gains. In figure 1 illustrates practical skill improvement



using electronic simulators. In figure-2 demonstrates learning effectiveness index across teaching methods.



The absorbed dose of ionizing radiation, which is essential for medical applications, is expressed as follows:

$$D = E/m$$

where D – absorbed dose (Gy), E – energy absorbed (J), m – mass of irradiated tissue (kg). This formula has been actively applied in virtual laboratory simulations, allowing students to model dose distribution in biological tissues.

Student's t- test :

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

where: X_1, X_2 – mean values of experimental and control groups, S_1^2, S_2^2 – variances, n_1, n_2 – sample sizes.

Effect size analysis indicated a strong impact of simulation- and video-based instruction, confirming its educational significance beyond statistical relevance.

Discussion

The findings provide compelling evidence that simulation- and video-based instructional design enhances both theoretical and practical learning in radiation–matter interaction courses. By enabling visualization and safe experimentation, electronic simulators mitigate the limitations of traditional instruction and foster meaningful learning. The integration of video-based clinical demonstrations further contextualizes abstract radiation concepts, reinforcing their relevance to medical practice. These results align with international research highlighting the effectiveness of technology-enhanced learning environments in complex scientific disciplines. Importantly, the study demonstrates that pedagogical effectiveness depends not merely on technological availability but on coherent instructional design grounded in learning theory.

Conclusion and Implications

This study confirms that simulation- and video-based instructional design significantly enhances learning outcomes in radiation–matter interaction courses at

medical universities. The proposed framework supports competency-based medical education and aligns with global trends in technology-enhanced learning.

The findings have practical implications for curriculum designers, educators, and policymakers seeking to modernize medical physics education. Future research should explore adaptive simulation environments and artificial intelligence–driven personalization to further optimize learning experiences.

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