2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

An Interactive web-based 3D Water Phantom Simulator for Teaching Dosimetry and Beam Data Acquisition

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ABSTRACT

Purpose: Hands-on training in absolute dosimetry and beam data acquisition is an important requirement in medical physics education, yet access to linear accelerators and water phantoms is often limited by clinical workload, and resource availability. The purpose of this work was to develop and evaluate a web-based, interactive 3D water phantom simulator that enables dosimetry education grounded in first principles.

Methods: A browser-based 3D water phantom simulation platform was developed using web technologies, requiring no software installation. The system provides virtual control of a linear accelerator, water phantom, electrometer, and scanning workflow, replicating the real dosimetry environment. Users can control beam energy, field size, dose rate, SSD, and monitor units. Three-dimensional ion chamber positioning is simulated with sub-millimeter resolution. In-plane, cross-plane, diagonal profiles, and depth-dose scans are supported for electron beams and for flattened and FFF photon beams. The platform was deployed for a limited period to medical physics trainees and trainers after a webinar-based demonstration.

Results: Learners were able to perform virtual dosimetry workflows, including chamber setup, beam scanning, and electrometer operation. Trainers reported that the simulation is useful for teaching and described it as an excellent teaching tool that will benefit students. Real-time visualization of depth-dose and beam profile curves improved conceptual understanding of beam characteristics and ionization chamber response. Feedback emphasized the educational value of the simulator and identified opportunities for improved clarity and functionality. Although feedback was from a limited number of participants, it provided actionable insights that suggested subsequent software enhancements, including clearer scan-direction visualization and enhanced electrometer behavior.

Conclusion: This web-based 3D water phantom simulator represents an innovative and scalable educational tool for teaching absolute dosimetry and beam data acquisition. Its interactive visualization, and ease of adoption support implementation across medical physics training programs, benefitting institutions with limited access to clinical accelerators

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INTRODUCTION

Hands-on training in absolute dosimetry and beam data acquisition is a cornerstone of medical physics education. However, access to clinical linear accelerators and water phantoms is often limited by clinical workload, resource availability, and safety constraints. This creates a significant educational gap, particularly for students and residents who require practical experience to develop essential competencies.

Simulation-based learning offers a scalable and risk-free alternative [1,2]. The purpose of this work was to develop and evaluate a web-based, interactive 3D water phantom simulator that enables dosimetry education grounded in first principles, providing an accessible and immersive learning environment.

METHODS AND MATERIALS

A browser-based simulation platform was developed using modern web technologies (Three.js for 3D rendering, Chart.js for data visualization, PHP/JS for interactivity), requiring no software installation and running entirely within a web browser.

The system replicates the real dosimetry environment, providing virtual control of:

Linear Accelerator: Beam energy (6MV, 6FFF, 10MV, 10FFF), collimator settings (symmetric and asymmetric jaws), dose rate (up to 2400 MU/min for FFF), SSD, and monitor units.

3D Water Phantom: Sub-millimeter positioning of a virtual ionization chamber in X, Y, and Z directions.

Electrometer: Real-time measurement of accumulated charge and simulated current, with field voltage and polarity controls.

Scanning Workflow: Automated scans for In-plane, Cross-plane, and Diagonal profiles, as well as Depth-Dose (PDD) curves.

The simulation was deployed and evaluated by a small group of medical physics trainees and trainers following a webinar-based demonstration, gathering qualitative feedback on its educational utility and functionality.

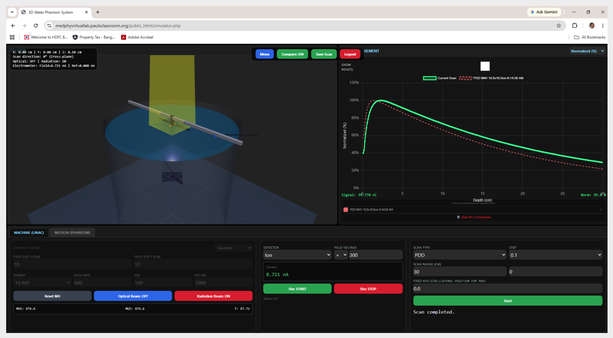

Figure 1. Comparison of percentage depth dose of 6 and 10 MV photon beams using the virtual water phantom.

RESULTS

Simulation Workflow:
Learners successfully performed a complete virtual dosimetry workflow, including chamber setup, beam parameter selection, scanning, and data acquisition.

Key Functionalities Demonstrated:

Realistic Beam Physics: The platform uses a pencil-beam dose calculation engine that generates data consistent with training expectations for different energies and field sizes.

Real-time Visualization: As scans are performed, depth-dose and beam profile curves are plotted live, improving the conceptual understanding of beam characteristics and ionization chamber response.

Interactive 3D Environment: Users can freely navigate the 3D scene, observe beam geometry, and manipulate the chamber position, providing a strong spatial understanding of the measurement geometry.

Comparison Tools: A built-in "Compare" mode allows users to overlay multiple scans, facilitating the study of parameter changes (e.g., energy, field size) on beam data. Figure 1 shows percentage depth dose comparison between 6 and 10 MV beams and Figure 2 demonstrates comparison of beam profiles for 10 FF and 10 FFF at 10 cm depth.

Trainer Feedback:

Described as an excellent teaching tool that will benefit students and address the gap in hands-on training.

Feedback emphasized its high educational value and identified opportunities for improved clarity and functionality, leading to subsequent software enhancements.

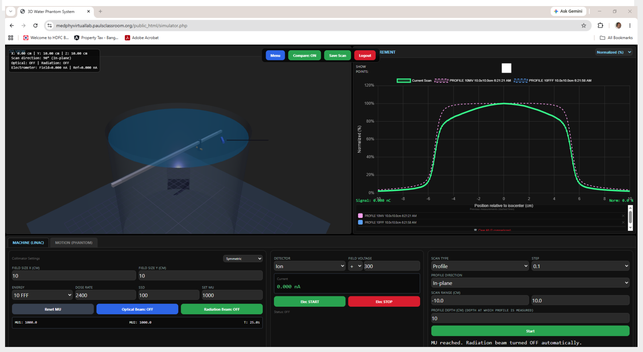

Figure 2. Comparison of beam profiles of 10 FF and 10 FFF photon beams at 10 cm depth in the virtual water phantom

DISCUSSION

This web-based simulator represents an innovative and scalable educational tool for teaching medical physics and training the students on dosimetry. By replicating the operational environment and physics of beam data acquisition, it bridges the gap between theoretical knowledge and practical application.

The positive feedback from trainers confirms the simulator's potential to enhance teaching/training by providing a risk-free environment for hands-on practice. The ability to visualize complex beam data in real-time helps demystify abstract concepts like percentage depth-dose and beam profiles.

The browser-based nature of the platform eliminates barriers to adoption, allowing students to access the simulation anytime, anywhere. Future enhancements will expand the dataset to include more beam qualities, refine the electrometer behavior, and potentially integrate it into formal medical physics curricula.

CONCLUSIONS

An interactive 3D water phantom simulator has been successfully developed as a web-based educational tool for medical physics.

It provides a realistic, scalable, and accessible platform for teaching absolute dosimetry and beam data acquisition.

The interactive, real-time visualization of 3D geometry and dose data significantly improves conceptual understanding for trainees.

This tool is a valuable resource for medical physics training programs, particularly for institutions with limited access to clinical accelerators, and has received positive initial feedback from educators.

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Click here to access the water phantom simulator : https://medphyvirtuallab.paulsclassroom.org/

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