STUDENTS' PERCEPTIONS OF MONTE CARLO SIMULATIONS AS A LEARNING TOOL IN RADIATION PHYSICS

L. Paixão[1], T.C.F. Fonseca[2]

[1] School of Medicine, Federal University of Minas Gerais, Belo Horizonte, Brazil
[2] School of Engineering, Federal University of Minas Gerais, Belo Horizonte, Brazil

Abstract— **This study evaluated students' perceptions of Monte Carlo simulations as a learning tool in radiation physics. Thirty-eight students were invited to complete an anonymous questionnaire, and thirty responded to it. Results indicated strong agreement that Monte Carlo simulations enhanced understanding and interest in radiation physics. Comments suggested increasing the course workload, improving clinical contextualization, and optimizing virtual machine performance. The findings support the use of Monte Carlo simulations as an effective, safe, and engaging tool for radiation physics experiments.**

Keywords— **Medical Physics, Monte Carlo simulation, Radiation Physics, Education, EGSnrc.**

I. INTRODUCTION

Teaching radiation physics presents conceptual challenges, especially in visualizing and understanding the processes of radiation interaction with matter. Implementing a hands-on radiation physics laboratory presents multiple challenges, including radiation shielding, safe handling of radioactive sources, equipment maintenance, and compliance with strict regulatory requirements. These practical and logistical constraints may limit students' access to real experiments, reducing opportunities for active learning and conceptual understanding. In this context, computational simulations provide a safe, cost-effective, and flexible alternative for illustrating complex radiation phenomena and complementing theoretical instruction. Monte Carlo computational simulations have been extensively applied in various fields of radiation and medical physics, including radiology, radiotherapy, nuclear medicine, and radiation protection, for nearly seventy years [1]. Therefore, the use of computational simulations with the Monte Carlo (MC) method may be an effective teaching tool, allowing students to explore complex phenomena in an interactive, safe, and accessible way. Similar initiatives have been reported [2-7].

Students in the Radiology Technology Program at the Federal University of Minas Gerais School of Medicine, Brazil, are required to complete a theoretical course in Radiation Physics. This theoretical course is particularly challenging and has the highest failure rate in the program, underlining the difficulties students face in mastering fundamental concepts. An elective "Computational Laboratory of Radiation Physics" course began in 2023 to engage students in practical, simulation-based experiments based on the book "Computational Experiments in Radiation Physics" [8,9]. In the laboratory course, the EGSnrc Monte Carlo code [10] was executed on a Lubuntu operating system [11] installed as a virtual machine using VirtualBox software [12]. Students practice eight experiments from the book, beginning with the discrete spectrum emission experiment and concluding with the electron range experiment. They are encouraged to observe the changes in the outcome of computational simulations according to proposed exercises and attempt to relate them to theory. Furthermore, comparisons with results published in the literature are regularly made and discussed in class. The course has a total workload of 30 hours per semester, with one 100-minute class per week. In addition, the authors encouraged undergraduate and graduate students under their supervision to develop work based on the experiments in the book. Some of these students used it as a tool in learning the Monte Carlo code they would use in their research.

This work aims to assess students' perceptions of the use of Monte Carlo simulations in learning radiation physics, considering aspects such as clarity of understanding of physical concepts, the contribution of the activities to learning, the level of engagement during class, and the applicability of the content to professional development.

II. MATERIALS AND METHODS

Students enrolled in the Computational Laboratory of Radiation Physics course between March 2023 and July 2025 were invited to participate in the study. Those who enrolled in the course but withdrew, either before or after the course began, were not invited. Undergraduate and graduate students who used the book "Computational Experiments in Radiation Physics" in their academic activities were also invited to participate. Invitations to participate were distributed by email. Participation in the study was voluntary, and all responses were collected anonymously. No identifying information (such as name, email address, or login) was requested or stored at any stage of data collection. A total of 38 students were invited to complete the questionnaire.

The data collection instrument consisted of a structured questionnaire (Google Forms) with statements evaluated on a five-point (symmetric) Likert scale (1 – strongly disagree to 5 – strongly agree) [13]. Responses were analyzed qualitatively, considering the trends of agreement with the following statements: (*i*) The use of Monte Carlo simulations facilitated the understanding of the concepts of interaction of radiation with matter; (*ii*) Computational activities helped to visualize phenomena that were previously only theoretical; (*iii*) The computing environment used was easy to understand and execute; (*iv*) The book Computational Experiments in Radiation Physics was useful in guiding the activities; (*v*) The use of simulations increased my interest in radiation physics. An optional comment section, with the question "Would you like to leave any comments or suggestions about the use of simulations in classes?" was included at the end of the questionnaire, allowing participants to express their thoughts about the course. Mean and standard deviation were computed for Likert-scale responses, and the margin of error corresponds to a 95% confidence interval, incorporating the finite population correction.

III. RESULTS AND DISCUSSION

A total of 30 responses were obtained out of 38 invitations, representing a 79% response rate. Table 1 presents the mean response for each statement evaluated. The associated margin of error for each mean is also shown, considering a 95% confidence level on a five-point Likert scale. Overall, the students' answers represent agreement (3.5 to 4.4 mean) and strong agreement (4.5 to 5.0 mean) with all questionnaire statements. The calculated margins of error were less than 5%, indicating that the answers are representative of the surveyed group.

Table 1: Students' responses

Response	Statement				
	i	*ii*	*iii*	*iv*	*v*
Mean	4.50	4.57	3.83	4.50	4.53
Margin of error	0.12	0.14	0.17	0.10	0.16

Statements (*ii*) and (*v*) had the highest mean scores, followed by statements (*i*) and (*iv*). These results indicate that the Monte Carlo simulation experiments enhanced students' understanding, comprehension, and interest in radiation physics. A similar finding was reported by Pater et al. [4]. Participants also agreed that the textbook used helped support the learning activities.

Statement (*iii*) had the lowest average (3.83) and the highest estimated margin of error (4.4%). Although there was general agreement that the computing environment used was easy to understand and execute, some students did not have a positive experience. Figure 1 shows the frequency of responses to statement (*iii*). Approximately 13% stated moderate disagreement, and 20% indicated neutrality or indecision.

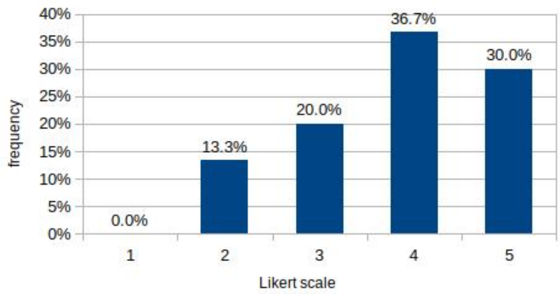

Figure 1: The distribution of student responses for statement (*iii*) on the five-point Likert scale

The virtual machine configuration on the lab computers used was not perfect. Some students experienced system crashes, requiring them to restart their computer or even switch to a different one. In some cases, students lost all their results and had to restart the experiment. The inability to communicate between the host machine and the virtual machine, due to lab configuration issues, prevented students from saving their results to removable media. This also caused frustration for some students. This result highlights a point that should be further addressed by this course or by anyone considering starting a similar course. In our case, according to the IT team, it was not possible to install the code directly on the host computers, which run the Windows operating system. For this reason, we chose to use a virtual machine system. If the host computers had run a Linux operating system, or if the IT lab had allowed the installation of the Monte Carlo code on Windows, the student experience could have been better. No complaints regarding the EGSnrc code were reported to the professor throughout the semesters.

Ten students (26%) used the comment section of the questionnaire to share their opinions. The comments included suggestions for increasing the course workload, improving the contextualization with clinical practice, providing a more detailed introduction to the Monte Carlo method itself, learning more about the Monte Carlo code used, and enhancing the performance of the virtual machine system. The suggestions made by the students are in line with those reported by Guatelli *et al.* [2] and Fielding *et al.* [7].

IV. CONCLUSION

This study evaluated students' perceptions of using Monte Carlo simulations as a tool for learning radiation physics. Results indicated strong agreement that the Monte Carlo simulation experiments enhanced students' understanding, comprehension, and interest in radiation physics. Participants also agreed that the didactic book used helped support the learning activities. Comments suggested increasing the course workload, improving clinical contextualization, and optimizing virtual machine performance. The findings support the use of Monte Carlo simulations as an effective, safe, and engaging tool for radiation physics experiments. This approach promotes active learning and can bridge the gap between radiation physics theory and practice. It can be integrated into medical physics, radiologic technology, nuclear engineering, and other programs.

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CONFLICT OF INTEREST

The authors declare that they are the authors of the textbook “Computational Experiments in Radiation Physics”, which was used as instructional material in the course evaluated in this study. The authors declare no other conflicts of interest related to this work.

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Contacts of the corresponding author:

Author: Lucas Paixão
Institute: Federal University of Minas Gerais
Street: 190 Professor Alfredo Balena
City: Belo Horizonte
Country: Brazil
Email: lucaspaixao@ufmg.br