The Effectiveness of Simulation in Biomedical Engineering Education: A Case Study

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Abstract: In the last decades, simulation has become an important tool in education, especially for the implementation of specific pedagogical approaches. In this work, we illustrate how simulation is implemented in a biomedical engineering course. Specifically, two simulation educational tools are currently used in the course to model and analyze healthcare models and health networks. To evaluate the perception of simulation by students on both student learning and subsequent professional careers, a survey was conducted. The survey, distributed through social networks, targeted students in the past decade who are now employed in regular job positions. 78 alumni completed the questionnaire and indicated a high level of perceived effectiveness of simulation and teaching course strategies, both in the study of course topics and in professional life.

1 INTRODUCTION

Biomedical engineering (BME) is dedicated to applying engineering principles to biomedical fields, focusing primarily on solving problems and improving health, care processes, and overall quality of life for patients (International Federation of Medical and Biological Engineers, 2024). In general, the BME degree course is based on the fundamentals of human anatomy and physiology and traditional engineering, offering then specialization in several areas such as medical instrumentation and imaging, biomechanics and biomaterials, biosignal processing, rehabilitation engineering, health informatics, and clinical engineering (Montesinos et al., 2023).

Problem solving is a key element of BME education, and a variety of pedagogical strategies are used, including problem-based (Long et al., 2022; Warnock and Mohammadi-Aragh, 2016), project-based (Setiawan, 2019; Rezvanifar and Amini, 2019), and experiential learning (Montesinos et al., 2023; Montesinos et al., 2022). To implement these methods, innovative BME curricula have proposed the use of simulation education tools (Singh et al., 2018; Singh et al., 2019). Simulation facilitates exploration and analysis of real-world challenges and encourages students to investigate and propose solutions, increasing students' motivation, collaboration, and participation (Magana and de Jong, 2018). In addition, the possibility of mixing synchronous and asynchronous learning, real-time feedback combined with the continuous monitoring of students' results, as well as the low cost, have promoted the use of simulation and its tools in the education of BME (Singh et al., 2018; Datta et al., 2013).

The literature provides numerous examples of simulation-based educational tools in BME. For instance, in response to COVID-19 pandemic restrictions, (Allen and Barker, 2021) suggested the use of an online virtual laboratory simulation to enhance the learning experience. Similarly, simulation learning activities were integrated in a BME course at the University of British Columbia (Harandi et al., 2019). The blended learning course combined lectures with practice activities using two specific simulation tools: ElectromagneticWorks for electric and magnetic field modeling and simulation, and PartSim for circuit analysis. Another recent study (Montesinos et al., 2023) introduced an experiential learning approach to equip BME students with transdisciplinary knowledge and skills aimed at improving hospital and healthcare operations. The research employed FlexSim Healthcare software to simulate and evaluate patient-centered processes within a hospital environ-

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ment. Additionally, (Cheng et al., 2023) investigated the integration of artificial intelligence tools, such as chatbots, to facilitate simulation activities in BME education.

This study aims to explore the application of simulation in a BME course and to evaluate how effectively the course and its methods translate to practical use in the field of BME. Specifically, it focuses on the Health Information Systems course offered in the first year of the Master's degree program in BME at the University of Naples Federico II. The course covers fundamentals of health systems and process analysis, modeling and analysis of health databases, networked health services, security, and privacy in health systems. It incorporates several simulation tools during traditional lectures and asynchronous activities. To investigate the longitudinal effectiveness of this learning approach, we developed a specific survey to measure the perception of students after they had entered the workforce.

2 MATERIAL AND METHODS

2.1 Course Overview

The course "Health Information Systems", offered in the first year of the Master's degree program in BME at the University of Naples Federico II, aims to explore concepts related to health information systems and their applications; a special emphasis is given to the organizational analysis of healthcare systems as an essential prerequisite for designing an information system. The course consists of five sections:

- Discrete event simulation for the analysis of healthcare organizational models.
- Network infrastructure services.
- Analysis and modeling of healthcare databases.
- Security and privacy.
- Web Accessibility.

At the end of the course, students can develop simple prototypes of healthcare information systems in the form of an organizational model and an IT network infrastructure. They acquire also professional knowledge for the analysis and design of business applications. Typically, the course is attended by an average of 130 students per year.

Moodle is used as a learning management system to structure the course. The Moodle course platform creates a learning environment that allows students to manage their study time efficiently, review lessons through systematic recording of all class activities, continuous interaction with the subject teacher, and effectively manage all technical issues related to the use of simulation tools (Magana and de Jong, 2018). The platform is not an alternative to traditional teaching but a support tool for implementing blended learning.

The course incorporates the use of simulation tools to improve understanding of key topics, provide practical examples, and then enhance the learning processes and support a more objective assessment of learning objectives, focusing more on the competencies acquired (Montesinos et al., 2023). The simulation educational tool and activities were applied to the first two chapters, which account for approximately 70% of the total course hours, while the remaining 30%, although with a particular emphasis on operational aspects, is organized more traditionally, through theoretical lectures, practical examples, and exercises.

Course objectives include understanding computational modeling and simulation techniques in health systems, examining how various parameters affect these systems, and evaluating the accuracy and reliability of simulation results.

2.2 Simulation Education Tools

In the first part of the course, students are introduced to the most common organizational models in healthcare. An overview of the most common techniques for static analysis of organizational systems is provided. These are essential for creating tools capable of artificially reproducing (simulating) some of the organizational models discussed in the introductory part of the course. To enhance understanding, the instructor employs simulated interviews to illustrate the functioning of traditional healthcare organizational structures, including hospital management, ward operations, and laboratory workflows. Subsequently, the students learn how to describe the concepts concisely expressed by stakeholders using typical Business Process Management diagrams, such as use cases and activity diagrams. They then progress to mastering the techniques and tools required to model not only the structural aspects but also the functionality of healthcare systems and their associated telecommunications infrastructure. This process equips them with practical, real-world skills that are essential for identifying, analyzing, and improving process-related challenges in professional environments.

Students can install educational tools on their laptops and collaborate in the classroom and remotely using the tools available on the Moodle platform.

2.2.1 Organizational Models Simulation

Simul8 (SIMUL8 Corporation, 2025), a discrete event simulation software, is used as an educational tool to model, analyze, and optimize complex processes and systems. It is particularly effective in healthcare settings, where it supports tasks such as optimizing patient flow, analyzing resource allocation, and simulating hospital processes.

With Simul8, users visually build simulation models using components like queues, work centers, and resources. The software also allows for the integration of real-world data from spreadsheets, databases, and other sources, ensuring models are both accurate and grounded in reality. Unlike traditional graphical process modeling tools, Simul8 enables users to replicate the live behavior of organizational systems in great detail. This means the software not only represents the structural aspects of a process but also simulates how its dynamics evolve over time. As a result, students can perform both "As-Is" analyses to evaluate existing processes and "What-If" scenarios to test potential improvements. This hands-on approach gives them practical experience with the healthcare challenges covered in the course and prepares them to address organizational problems in real-world contexts.

To ensure sufficient practice, students have access to a full version of the software for six months. This extended timeframe allows them to develop the necessary skills and achieve a high level of proficiency.

2.2.2 Network Systems Simulation

For the infrastructure part, students practice using Cisco Packet Tracer (Cisco, 2025). This is a simulation tool for designing, configuring, and examining network operations in a virtual environment. This interactive method can facilitate understanding of telematic network operations and related problems.

Through a partnership between Cisco and the University of Naples Federico II, students benefit from access to an educational version of Cisco Packet Tracer.

2.3 Exam Procedure

The final exam for these two learning sections provides the design and development of a simulation model and network infrastructure of a healthcare system using the proposed simulation tools.

In the Moodle course platform, the instructor adds an activity called "assignment," which allows the student who intends to take the exam to submit a short document explaining the context, process, and related issues of the healthcare system that will be simulated. Before the exam, the instructor evaluates and, if appropriate, approves the document, authorizing the student to independently develop the required simulation model. The model will then be discussed during the exam.

2.4 Longitudinal Qualitative Evaluation

The effectiveness and satisfaction of students with this teaching approach are extensively demonstrated through the teaching evaluation questionnaires that students fill out every year before taking the exam. However, these questionnaires do not provide any information regarding students' perceptions of the skills they have acquired once they enter the workforce and have the opportunity to experience the actual impact of the skills they have attained.

A questionnaire has been prepared to evaluate the impact of the applied teaching methodology on the professional life of the students. The questionnaire was filled in exclusively by graduates of the BME at the University of Naples Federico II, where the course in Healthcare Information Systems is compulsory. The first part of the questionnaire asked for general information, specifically the number of years since graduation, the sector of employment, and the number of months from graduation to the first job. The second part of the questionnaire was designed to investigate the perceived effectiveness of the course content and simulation tools in the professional career. Specifically, participants answer using a 5-point Likert scale ranging from: absolutely no to absolutely yes.

Collecting data from students after they leave university can indeed be challenging. Once students graduate and enter the workforce, they may become geographically dispersed, making them difficult to track and reach for follow-up studies. In addition, they may become less engaged in university-related activities and less likely to participate in surveys or research studies. For this reason, the questionnaire was administered through social channels, specifically Facebook and Linkedln, to facilitate the dissemination of the survey and reach the largest number of students. The survey was anonymized and participants gave their consent before participating in the survey.

3 RESULTS

A total of 78 answers were collected. Most of the participants (44%) who completed the questionnaire graduated more than 5 years ago, while 42% graduated more than 10 years ago and 14% graduated one year ago. 23% of the participants work in the health informatics sector, 22% in clinical engineering, 24% in consulting, 10% in services, 4% in sales, 3% in manufacturing, and 14% in other sectors. 29% of the participants found a job within two months of graduation, 34% found a job after two months, and 37% found a job before graduation.

The results of the survey questions about the effectiveness of the course and the simulation are shown in Fig. 1, 2, 3, 4, 5, 6, and 7.

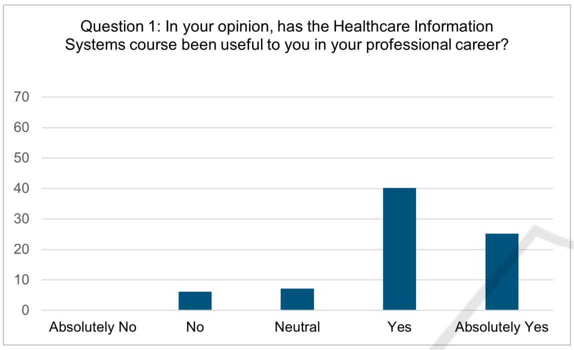

Figure 1: Results of Question 1. The figure illustrates the responses to Q1 regarding participants' perception of the course's overall usefulness.

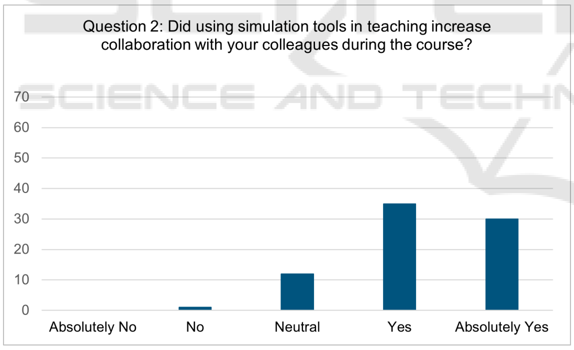

Figure 2: Results of Question 2. The figure illustrates responses to Q2, which assessed whether the use of simulation tools during teaching enhanced collaboration with colleagues throughout the course.

4 DISCUSSION AND CONCLUSION

Simulation has become a critical component of BME education, enabling the modeling, analysis, and optimization of complex healthcare systems (Montesinos et al., 2023). In this study, we propose a practical example of simulation implementation in BME education. Specifically, a learning experience was designed for a Master's course in BME using two educational simulation tools: Simul8 and Cisco Packet Tracer. These tools allow students to analyze and optimize healthcare systems. The educational activities are organized and managed into the Moodle course.

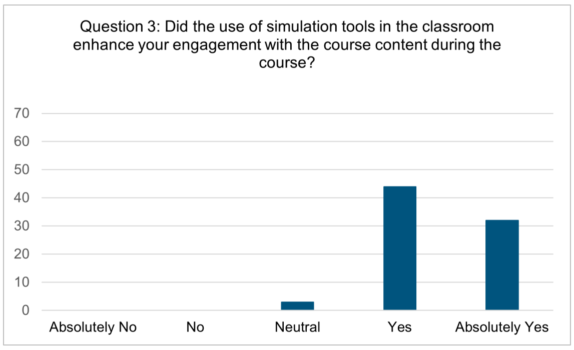

Figure 3: Results of Question 3. The figure shows responses to Q3, which evaluated whether the use of simulation tools in the classroom enhanced student engagement with the course content during the course.

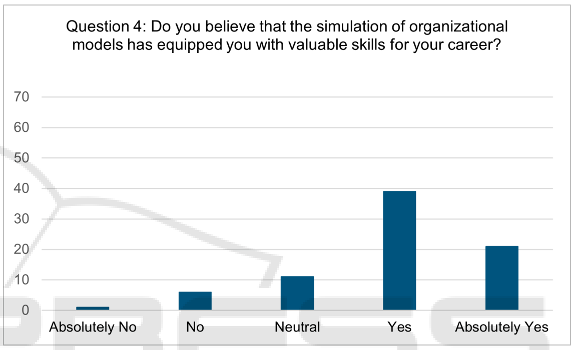

Figure 4: Results of Question 4. The figure shows responses to Q4, which examined whether the simulation of organizational models provided participants with valuable skills for their careers.

To investigate the usefulness of simulation use in BME, a specific survey was created. The survey revealed that almost all of the participants have been working for more than 1 year and therefore have a clear perception of their work needs. In addition, it should be noted that the sectors of employment are quite diversified, confirming that BME graduates are very versatile professionals who find employment in work environments far from the world of health. (Sloane and Hosea, 2017). The majority of participants reported that the course content was useful in their professional careers (Fig. 1). As shown in Fig. 2 and 3, most participants acknowledged the role of simulations in enhancing collaboration with colleagues and fostering greater engagement in course activities. Similarly, participants indicated that the

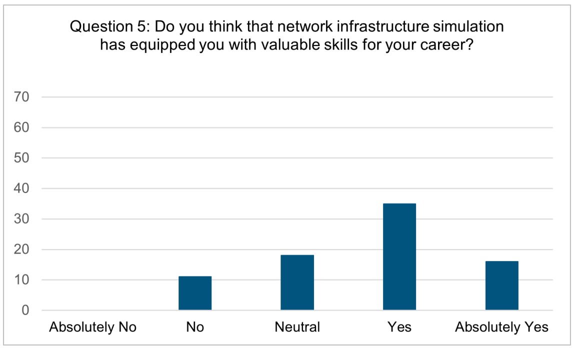

Figure 5: Results of Question 5. The figure illustrates responses to Q5, which evaluated whether the simulation of network infrastructure provided participants with valuable skills for their careers.

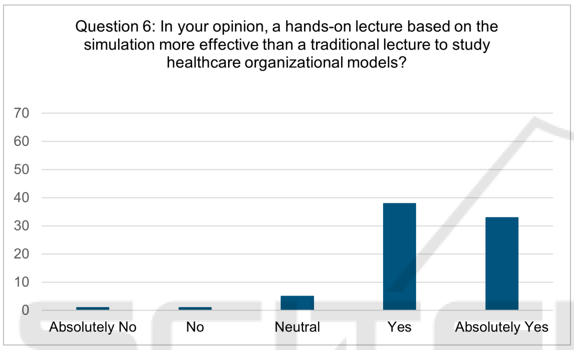

Figure 6: Results of Question 6. The figure shows responses to Q6, which assessed whether a hands-on lecture based on simulations is perceived as more effective than traditional lectures for studying healthcare organizational models.

simulation had a significant impact on their career development (Fig. 4 and 5). In addition, as illustrated in Fig. 6 and 7, hands-on lectures incorporating simulations were rated more favorably than traditional lectures for studying course content. This preference was emphasized in participant feedback, with several suggestions to use simulation and its tools for multiple courses in the curriculum.

To our knowledge, this is the first study to assess the perceived usefulness of simulation in biomedical engineers and to evaluate the impact of the BME course and its strategies with a longitudinal perspective, not limited to the course feedback questionnaire typically administered at the end of a semester. Consistent with the literature (Singh et al., 2018; Mukherjee and Barker, 2021; Adam and Hashim, 2014; Lozano-Durán et al., 2023), our results indicate a positive response to the use of simulation tools both in learning and then in work settings. Furthermore, although the proposed simulation activities are applied in a specific BME course, the current results confirm the usefulness of integrating active ped-

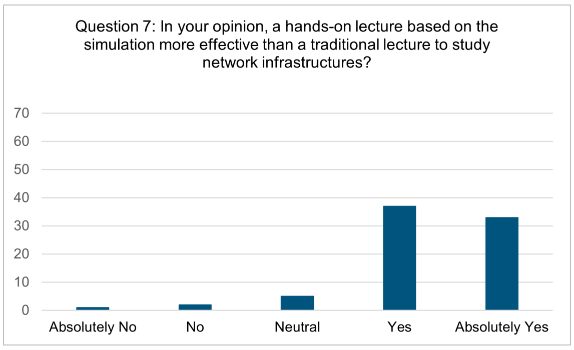

Figure 7: Results of Question 7. The figure illustrates responses to Q7, which evaluated whether a hands-on lecture based on simulations is perceived as more effective than traditional lessons for studying network infrastructures.

agogical strategies and techniques in BME education (Cyrus Rezvanifar and Amini, 2020; Rezvanifar and Amini, 2019). This integration effectively supports the transfer of knowledge from lectures to practical applications in real-world settings (Singh et al., 2018). Moreover, as the survey results show, simulation can be an effective and versatile tool for improving the climate of collaboration and engagement in the classroom, and thus the psychological well-being of students (Singh et al., 2018; Singh et al., 2019; Magana and de Jong, 2018). The lessons can become an opportunity not only to receive knowledge from the instructor but also to discuss and work together on concrete applications using these tools (Montesinos et al., 2023).

It should be noted that implementing simulation-based active learning modules poses several challenges for instructors, who need to review and re-analyze course activities and documentation. However, as emphasized by (Mukherjee and Barker, 2021), a great deal of effort is required only in the first edition of the course; subsequently, the re-implementation of simulation activities becomes more manageable. We have successfully managed this process of re-implementation, largely due to the Moodle platform.

The present study has several limitations. First, although the sample of 78 participants provides valuable insights, the relatively small sample size and self-selective nature of social media recruitment may not be fully representative of the entire BME graduate population. In addition, the use of purely qualitative measures based on participants' subjective perceptions, while providing important findings, could benefit from integration with more objective quantitative measures to assess the actual impact on professional careers. Another limitation relates to the simulation tools used. The use of a non-open access simulation tool may reduce its replicability in other educational contexts. However, it is worth noting that the simulation programs are free to students through the educational version, resulting in minimal cost to the university.

Further research should address these limitations by expanding the sample size and assessing the longitudinal efficacy of simulation-based learning in BME education, particularly its impact on career outcomes. This includes the evaluation of long-term career effects and the use of simulation capabilities in the workplace.

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