Smart Healthcare Engineering: An Innovative Educational Framework for Training Future Healthcare Engineers

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Abstract

The digitalization of healthcare systems and the increasing complexity of medical infrastructure require engineers capable of operating at the interface between engineering and healthcare. This study presents the Erasmus+ project Smart Healthcare Engineering (SHEng) that aims to create an educational framework that combines engineering, healthcare technologies, hospital management and practical training in real medical environments. The concept brings together universities and healthcare institutions from Romania, Spain and Türkiye to develop innovative learning resources, intensive international training program and an open e-learning platform dedicated to healthcare engineering [1]. The educational model integrates theoretical instruction, laboratory activities, hospital based case studies and collaborative international learning experiences. A key component of the project consisted of intensive training program organized in Spain and Romania, involving students from different academic and cultural backgrounds. The results showed clear improvements in students' knowledge and understanding of healthcare engineering topics, while also highlighting the positive impact of transnational and multidisciplinary learning environments on student engagement and performance. The study outcomes include innovative educational materials and a new methodology for competency based training in healthcare engineering. The results indicate that international collaborative learning, supported by digital educational tools and practical hospital exposure, is a good method for preparing future engineers to meet the technological challenges of healthcare.

Keywords: *Healthcare engineering, international training, healthcare management*

1. Introduction

The healthcare systems are changing very quickly and now hospitals are no longer only medical facilities where doctors and nurses provide care but are a complex technical environment that depends on medical devices and digital systems, water systems, ventilation systems and many other support services. In this context, engineering has a key role in healthcare and without well designed, maintained and safe technical systems, the medical care cannot be delivered at the required level of quality.
Healthcare engineering can be understood as the application of engineering knowledge, technical management and problem solving methods to healthcare system, being closely connected with hospital engineering. The engineer that works in the hospital is the professional that can support decisions related to technology selection, safety, maintenance, risk reduction, regulatory compliance, user training and the integration of medical technologies into clinical workflows. Yadin D. [2] shows the major impact of clinical engineers and Health Technology (HT) on global patient outcomes. In many hospitals, engineering departments contribute directly to patient safety, cost control and the effective use of medical technologies.
The role of engineers in hospitals has become more visible because of the increasing number and complexity of medical devices. Imaging systems, monitoring equipment, ventilators, laboratory equipment and digital health platforms require permanent technical support [3]. These technologies must be selected, installed, calibrated, maintained and used correctly because a technical failure can affect diagnosis, treatment, patient safety or the continuity of medical services. For this reason, the hospital engineer must understand not only the technical characteristics of equipment, but also the clinical context in which the equipment is used.
At the same time, hospitals are under strong pressure to reduce energy consumption, optimize resources, improve patient flow, control infections, reduce risks and integrate digital solutions. These challenges cannot be solved only by medical staff. They require interdisciplinary teams, where

engineers, doctors, nurses, managers and IT specialists work together. Studies in clinical engineering and healthcare technology management show that engineering professionals can have an important impact on the performance of healthcare systems, especially when their activity is connected with patient outcomes and hospital management [4].

Digital transformation is another important factor that changes the role of engineering in healthcare as uprising technologies are now part of healthcare facilities [6]. Artificial intelligence (AI) is now used in image processing and interpretation but also in data analysis from sensors spread in the hospital areas [8]. These technologies create new opportunities, but also new risks in terms of cybersecurity, data flow, equipment connectivity, user acceptance and the validation of digital health solutions [9,10].

The Digital health cannot be implemented only by buying technology but requires training, organizational change and technical support from specialized engineers.

A graduate who wants to work in healthcare engineering should understand medical technology, hospital infrastructure, safety, quality management, digital systems, sustainability and communication with healthcare professionals. This type of profile is not easy to develop through traditional engineering profile from EU Universities. The current engineering curricula are often organized by discipline, such as materials, mechanical engineering, electrical engineering or industrial engineering. However, the hospital environment is interdisciplinary by nature. The same technical problem can include aspects of mechanics, electronics, materials, software, standards, hygiene, ergonomics, maintenance and human behavior. For this reason, engineering education must create learning situations that are closer to the real conditions of healthcare practice. Students need to see hospitals not only as users of technology, but also as complex systems where engineering decisions have direct effects on medical activity. Experiential learning, project based learning and workplace learning are useful approaches in this direction. They allow students to apply knowledge in real or realistic contexts, to work in teams, to solve open problems and to understand the connection between theory and practice [5].

Therefore, education must prepare students to communicate across professional boundaries. Interprofessional education has been widely discussed in health professions education, especially for improving collaboration and patient care [11-13]. Although engineering students are not always included in classical interprofessional healthcare training, their future role in hospitals makes such preparation important.

This study presents the concept of a project developed in this context. The project responds to the need for a new educational framework able to prepare engineering students for the technological and operational challenges of modern hospitals. It brings together universities and healthcare institutions from Romania, Spain and Türkiye and proposes an interdisciplinary model based on international collaboration, intensive training program, hospital visits, laboratory activities, e-learning resources and practical case studies [1].

The main idea of the study is that healthcare engineering cannot be taught only from books. The students need to understand that healthcare engineering is not limited to medical devices. It includes maintenance, quality, risk management, metrology, medical gases, corrosion, materials, energy efficiency, digital systems, occupational safety as well as many other technical aspects that support hospital activity.

The purpose of this paper is to present the educational methodology and implementation of the SHEng concept, with a focus on the activities developed during the intensive training program and on the general educational impact observed during the project.

2. Methodology

The educational methodology from this study was designed to combine theoretical learning, practical hands on demonstrations, hospital visits and international collaboration. The project was not built as a classical course, but as a learning ecosystem that includes intensive training programs, learning materials, and hospital case studies. The project consortium includes higher education institutions and healthcare organizations from Romania, Spain and Türkiye. This partnership is important because it connects the academic perspective with the practical needs of hospitals. Universities provide teaching expertise, research knowledge and student groups. Hospitals provide real examples, infrastructure, clinical context and professional experience. Figure 1 shows the main concept of the Smart Healthcare Engineering concept.

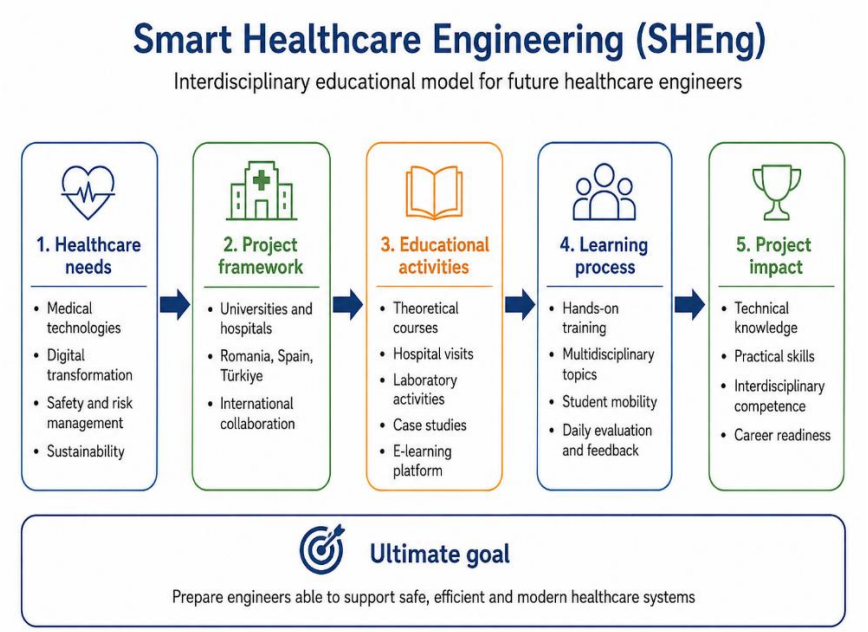

Fig. 1. Smart Healthcare Engineering educational concept

The Smart Healthcare Engineering concept is based on two different directions. One is the intercultural interaction between students and teachers and on the modern teaching activities organized as intensive training sessions. The main concept is based on organizing intensive training programs for small groups of international students from engineering fields and prepare them for a future career in the healthcare domain.

The training sessions were designed as international learning experiences, where students from different universities participated in lectures, practical sessions, laboratory work and hospital visits. The training program was not limited to a single discipline but included topics from healthcare engineering, medical technology, hospital infrastructure, materials, maintenance, quality, safety and digital systems.

Fig. 2. During the teaching session at Dr. Negrin Hospital, Las Palmas de Gran Canaria, Spain and at Transilvania University of Brașov, Brasov, Romania

The general structure of the intensive training programs included 12 daily teaching activities, technical presentations, practical demonstrations and evaluation activities before and after each teaching sessions. The topics were selected to show the broad role of engineering in hospitals, including hospital risk areas, protection of staff and patients, role of the healthcare engineer, medical equipment and machinery, metrology, communication between engineers and medical staff, corrosion in hospital installations, stainless steels used in healthcare, medical gases, oxygen pipelines, energy saving, Legionella prevention, SCADA systems, maintenance indicators, non-destructive testing and safety procedures.

A strong element of the methodology was the use of hospital based learning that helped students to connect abstract technical concepts with real hospital applications. For example, i) a topic such as corrosion becomes more relevant when students understand its effect on hospital installations, ii) a topic such as maintenance becomes more concrete when students see how a failure can affect a medical service, iii) a topic such as medical gases becomes clearer when students see the pipeline route and understand the importance of oxygen supply for patient care.
The teaching activity also included case studies that have been built around equipment maintenance, hospital infrastructure, energy consumption, technical risk, safety incidents, medical gas systems, infection prevention or communication between departments. These case studies help students develop problem solving skills and understand that hospital problems are rarely simple because often involve organizational and human factors.
The teaching-learning methodology included student evaluation based on multiple-choices questionnaires and self-assessment tests used daily to monitor learning progress and student perception. The aim of the evaluation was to identify changes in student knowledge, engagement and understanding of healthcare engineering topics.
A key element was the adjusting of the course level each day based on the results of the evaluation made on the previous training day. In this way, the teachers knew what were the strong and week point in the students knowledge. This educational methodology and structure is aligned with current trends in engineering education, where students are expected to develop not only technical knowledge, but also transversal skills [14, 15]. In the SHEng concept, these methods were adapted to the specific field of healthcare engineering.

3. Results

The first important result of the project was to identifying the complexity of the healthcare engineering field and creation of an interdisciplinary educational framework for healthcare engineering.
This teaching - learning concept connects engineering education with real hospital needs by offering to students the possibility to understand how technical systems support medical activity and how engineering decisions can influence safety, efficiency and quality in hospitals. The project also helped clarify the professional role of the healthcare engineer as a link between technology, infrastructure, management and clinical practice.
A visible result after the training sessions was the increased awareness of students regarding the complexity of hospital infrastructure as many engineering students being familiar with industrial systems, but not fully understand the technical complexity of hospitals.

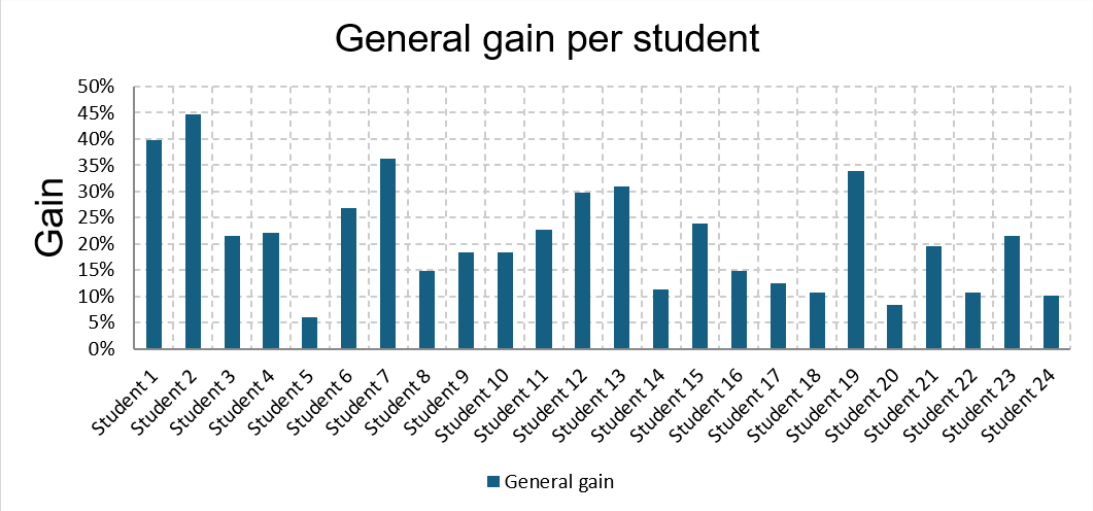

Fig. 3. General gain per student during the Smart Healthcare Engineering training activities.

Figure 3 presents the general learning gain obtained by each of 24 students after participation in the Smart Healthcare Engineering 12 days of training activities. The gain was calculated as the difference between the initial and final level of knowledge, expressed in percentage points, as follows:

$$Gain_i = Post\ i - Pre\ i \quad (1)$$

where:
$Post_i$= score of student *i* in **Test general after** the training
Pre_i= score of student *i* in **Test general before** the training

The results show a positive gain for all students, which indicates that the educational activities contributed to an improvement in the general understanding of healthcare engineering topics.
All students show positive general gain after the training activities, and most gains appear to be between 10 and 30 percentage points, with several higher values around 30% to 45%. At the same time, the graph of fig. 3 shows some variation between students. This variation is normal in an international training program, because participants had different academic backgrounds, previous knowledge, learning styles, levels of attendance and engagement during the activities. Students with lower gains should not automatically be interpreted as having poor performance, because a smaller gain may also be related to a higher initial score before the training.
The observed feedback from students and teachers indicated that the practical and international character of the project was appreciated. Students were interested in topics that connected engineering with real hospital problems. They also showed interest in understanding how medical technologies are used, maintained and managed and some students expressed an interest in following a career in healthcare engineering. This is important because many students do not initially associate their engineering education with healthcare.

4. Discussion

The SHEng project and educational concept confirm the importance of practical and interdisciplinary education in healthcare engineering. Modern hospitals require engineers who can understand both technical systems and healthcare needs. This type of professional cannot be prepared only through traditional lectures as the students must be exposed to real problems, real infrastructure and real communication situations. The project responds to this need by combining classroom learning with, hospital visits, hands-on activities and international collaboration.
One important aspect is the role of hospitals as learning environments. In many instances the hospital as learning environment is associated with residents, doctors and nurses that are involved in the medical act. Hospitals are sensitive institutions where patient safety, confidentiality, hygiene and clinical activity are priorities and the learning activities for the technical part of the facility often raise issues in affecting the daily medical work. The content of the classes must be organized in a clear way and on site visits should be spot on, so that students do not feel overwhelmed by the large amount of information.
The training sessions also had some limitations. The different academic background of the students was one of the main challenges. The participants came from different countries, universities and years of study. In this particular case, the students were from industrial engineering, materials science, electrical engineering and bioengineering and were enrolled in the first, second or third year of study. This diversity was useful for interdisciplinary learning, but it also required the teachers to adapt the level and rhythm of the courses. Another challenge was the English language. Even if the students had a good level of English, the specific terminology used in healthcare engineering created some difficulties during the learning process. This issue was addressed by providing explanations in simpler terms and when necessary, by translating key concepts into the students' mother language during the classes. Student feedback also indicated that the training sessions were long and at the end of the day it was more difficult to maintain attention and focus. Another challenge appeared during the hospital visits. Engineering students are not future medical staff, and spending too much time in a hospital environment, where patients are present, can be difficult.

5. Conclusions

The Smart Healthcare Engineering project presents an interdisciplinary educational model for preparing engineering students to understand and support modern healthcare systems. The concept responded to the growing need for engineers who can work in hospitals and contribute to medical technology management, infrastructure, safety, maintenance, digital systems and sustainable healthcare services. The teaching methodology creates a relevant learning environment where students can connect engineering knowledge with real healthcare applications. The activities implemented in Spain and Romania showed that students benefit from direct practice to hospital infrastructure, practical demonstrations and collaboration with colleagues from different countries.

The SHEng model can be adapted by other universities interested in healthcare engineering, biomedical engineering, industrial engineering or hospital technology management. Future work will include the integration of the quantitative evaluation results, the further development of the e-learning platform and the expansion of collaboration between universities and healthcare institutions.

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