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Innovation Report

Transnational learning and teaching activities: Smart Healthcare Engineering

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ABSTRACT

The new maintenance engineers become self-taught and learn from daily dedication, from solving repetitive problems, from exchanging experiences with a colleague, from reading a recommended book and little else. Their own experience has been the main reference for maintenance professionals who have not given up and have become experts. And within the maintenance activities, sanitary engineering plays a very important role. Through the Smart Healthcare Engineering project we have facilitated a close connection between 3 universities and 3 hospitals from 3 countries (Spain, Turkey and Romania), which benefit from each other's experience, transferring the know-how available in a single country. The study involves 7 students from each university, meaning that 21 students have worked and studied together for 2 weeks in Spain in the field of healthcare engineering. The chosen hospital was Dr. Negrin Hospital from Gran Canaria. Results at the organizational level include the modernization of content and the provision of resources for healthcare engineering training, the introduction of innovative educational concepts in healthcare engineering and the integration of blended learning methodologies in practical teaching and training activities. A tighter connection and transnational collaboration were established between European hospitals and universities in healthcare engineering, together with unrestricted access to routinely updated information. The specific results for each participant indicated their capacity to engage in the intricate processes of repair and maintenance within a practical context, making real-time judgments on-site.

1. Introduction

An indication of the level of development of a city is undoubtedly the quality of the hospitals located in it [1]. The complexity of hospital facilities and their maintenance is a challenge for healthcare managers [2,3], derived from regulatory controls and healthcare production standards. As a consequence of these indicators, there is a high number of operational failures in their functioning [4], which has a direct impact on the poor quality of hospital services, creating a direct harm to patients. To meet these challenges, healthcare managers must have skills in strategic planning [5], resource management, interdepartmental coordination and risk management [6]. In addition, it is essential to invest in facility management technology and staff training to ensure efficient and safe operation of hospital facilities [7].

It has been demonstrated that comfort and safety in the operation of hospital facilities are directly related and are fundamental aspects of providing effective and quality medical care [8]. A safe hospital environment not only benefits patients, but also medical and support staff. This includes the implementation of occupational safety measures, such as personal protective equipment, safety protocols for handling medical equipment and hazardous substances and the prevention of accidents and injuries in the workplace [9].

Good maintenance means having trained engineers to meet the demand for breakdowns and problems that arise in the daily operation of a hospital. Hospitals are subject to a variety of rules and regulations that set standards for facility maintenance and safety. Specialized engineers understand these regulations and work to ensure that the hospital complies with all legal and safety requirements. Failures in hospital facilities can be catastrophic [3]. Studies on the management of maintenance processes by engineers have revealed multiple causes of failure in hospital facilities, stemming from their lack of experience in such complex facilities [10]. Maintenance work is fundamental and

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well-trained staff is essential for optimal performance and quality, as well as for providing good continuity of service in hospital buildings without affecting patient satisfaction [11]. Effective maintenance involves not only repairing broken equipment, but also optimizing its performance and efficiency. Trained engineers can identify areas for improvement in facilities and propose solutions to optimize the use of resources such as energy, water and materials [12]. The training of engineers specialized in hospital maintenance is essential to ensure safe and efficient operation of facilities, prevent catastrophic failures and comply with applicable standards and regulations.

Distance learning, originating from the pandemic situation was the only option for postgraduate training of hospital maintenance engineering students. One of the main causes of failure in distance learning is the lack of creative personality development [13], which can only be acquired when practicing in real situations, in workshops, industrial factories, smart buildings, electronic technology industries, etc., the sensations of live engineering are not comparable with distance learning [14].

It is an obvious fact that many of the engineers who finish their studies at university are going to start their professional life working in different areas of maintenance. And many of these professionals have entered the maintenance activity without having any academic reference [15], without knowing the basic concepts and principles of action within this activity. They become self-taught and learn from daily dedication, from solving repetitive problems, from exchanging experiences with a colleague [16], from reading a recommended book and little else. Their own experience has been the main reference for maintenance professionals who have not given up and have become experts. And within the maintenance activities, sanitary engineering plays a very important role.

The personal development of an engineer is limited by the technological development he faces in his professional career. In this sense, the engineer's creative training forms a fundamental part of the teaching-learning process [16] and will be his or her future potential to face new challenges in hospital facilities. An engineer has to be adaptive, imaginative and creative [17–19], because technology is constantly evolving, technical controls are changing and becoming more complex, support and control software are becoming more specific [20], machines are more efficient, automation of equipment and facilities are in continuous renewal, the incorporation of new materials with different energy resources to satisfy more efficiently, communications between equipment and maintenance personnel, everything evolves and changes to total productivity, which implies a newer and more adaptive maintenance method [21]. The creative activity of each individual is a valuable and developable property.

The centralization of Smart healthcare tasks involves several interdisciplinary fields, including robotics [22], with an example currently widely used to dispense medicines between the different sectors and specialties of the hospital area. The integration of robotics in the centralization of tasks in the field of smart healthcare contributes to improving operational efficiency, accessibility to medical care and the quality of services provided. In addition, it leverages technology to address challenges such as medical staff shortages and care for remote or marginalized populations. Another area in which this field is based is in the control sensors of basic functions of the human body, such as autonomous respirators, blood saturation control, etc., computing has been one of the fundamental pillars in the evolution of advanced control software and quantum computing [23], this is part of the present of intelligent healthcare, with a high degree of technological advancement and a permanent and continuous development. The transformation from the analogue to the digital world in the last 30 years has been based exclusively on information and communication technology (ICT) [24], as an example of this advance are remote-controlled surgeries via mobile devices or tablet [25], biomedical engineering together with the development of communication technologies makes control increasingly efficient. The introduction of the Internet of Things (IoT) [26–28] and Industry 4.0 (I4.0) [29], as well as the development of wireless connectivity, with 5 G systems continuously evolving and integrating more and more external control devices through more complex data networks [30,31], operating more efficiently and with a more complex degree of maintenance, in which data security systems have to be included at a higher rate of development [32]. The new intelligent control systems included in recent years in the hospital maintenance industry involve the creation of new data storage systems [33], the concept of big data comes into play in a new cloud-based indirect control system [34–37]. The introduction of artificial intelligence is starting to gain notoriety in decision making and is very recurrent and applicable to the maintenance of intelligent buildings such as hospitals [38–40].

From this new technological evolutionary situation, dictated by today's society s new engineers have to master several languages, with the ability to understand technical documentation, interpret manuals, regulations and documentation in a language other than their own, thus creating a new globalized, adaptive and creative engineer [41,42].

Despite the essential role of proficient engineers in upholding hospital facilities and ensuring respect to safety standards, an important obstacle persists in sufficiently preparing engineers to address the requirements of swiftly advancing technologies and complex maintenance systems within hospitals. Current research underscores shortcomings in the practical and innovative training of engineers, especially within distance learning frameworks, which restrict hands-on experience and the cultivation of vital adaptable and creative problem-solving abilities. Moreover, although innovations in technologies like IoT, Industry 4.0, robotics and AI are rendering hospital maintenance increasingly intricate and data-centric, there is a lack of research regarding the effective incorporation of these advancements into the training programs for hospital maintenance engineers. This gap highlights the necessity for novel educational strategies that connect theoretical knowledge with practical application, cultivating globally competent, adaptable, and creative engineers equipped to face the problems of contemporary medical facilities.

Through SHE study, we will easily facilitate a close connection between 3 universities and 3 hospitals from 3 countries, Spain, Turkey and Romania, see Fig. 1, which will benefit from each other's experience, transferring know-how available in one single country. International collaboration in the field of health and education can be incredibly enriching, enabling the exchange of knowledge, best practices and resources between different countries and cultures.

2. Project description

2.1. Procedure

The state of the art in developing basic competences in engineering students today is to take advantage of technology as well as knowledge to improve both learning and the guided teaching process. Taking into account that this study has been based on the concept of "Learning and development" [43], it enhances the value of practice more than theoretical teaching [44], with this form of teaching it is assessed that most of the learning is done informally, 70 % of the work is learned from tasks in which there is a challenge to overcome, 20 % of the learning is achieved by sharing knowledge among peers, while the remaining 10 % is from formal or regulated learning. This 10–20–70 system [45], demonstrates that most of the experiences are acquired in face-to-face activities, if the part of peer learning is added, 90 % of non-formal or informal learning is reached [46]. Informal learning refers to the conducted learning experience, with no apparent structure of knowledge integration in the student's training process, becoming a system of spontaneous and natural experience acquisition [47], sometimes creating a creative leader [48,49]. Each student must assess the learning carried out by each partner [50], supervising the progress of each peer and adjusting the time spent at each stage of the learning process until the objectives set individually are reached [51].

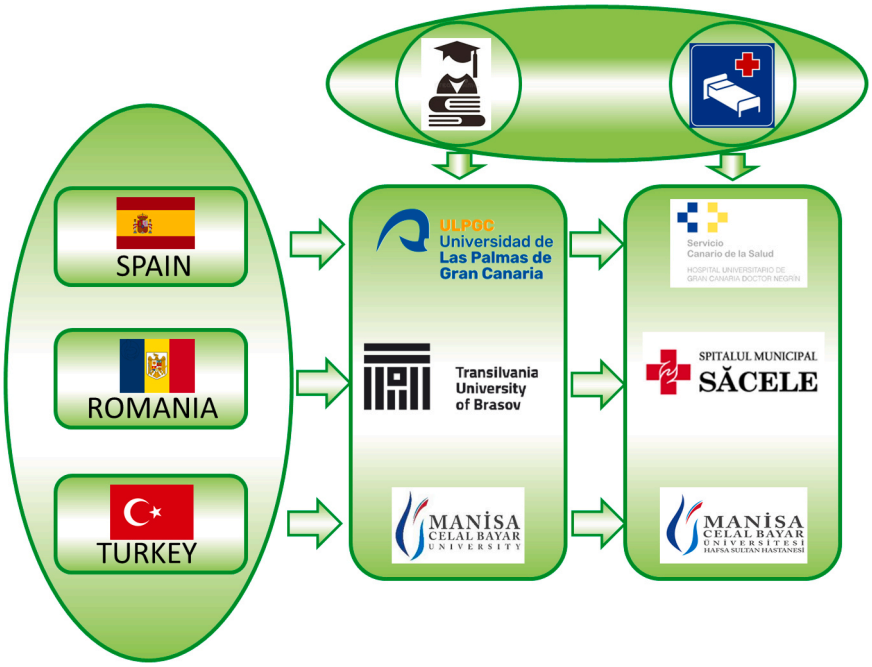

Fig. 1. Participating organizations.

The final stage of the training program includes practical training activities, as well as work specific to the actions carried out during the training period, will have a direct impact on their creative potential [52, 53]. This collaborative work between students from different countries of origin and the same training has a positive impact on the final result of the individual preparation, reflecting in parallel the needs, advantages and disadvantages of each country in the system of intelligent healthcare organization and for this purpose it is necessary to develop the creative potential by taking on new real challenges. The training of the student as a productive force is the result of the evolution of technology and its applications to the industrial world. The sense of this study is based on the development of the creativity of the person with technical knowledge [15], applied to the maintenance of hospitals in 3 work environments where the common nexus is the sick. Each new engineer will have his own development depending on the technology he encounters in his professional future [54] and they will be able to find creative solutions to new situations and very different from his educational environment [55] and thus be able to develop the appropriate competences in a very technical and technological world.

2.2. Objectives

There are three main areas of the objectives (see Fig. 2): first is regarding higher education, the second is regarding the social inclusion and the third but not the last is regarding the innovative practices in a digital era.

2.2.1. First objective: higher education (HE)

Promoting and rewarding excellence in teaching and skills development. The purpose of SHE is:

- to encourage and facilitate exchange of information and experience in the broad field of hospital and healthcare facility design, engineering and maintenance.
- to promote, develop and disseminate hospital engineering technology
- to compare international experiences
- to promote the principle of integrated planning, design and evaluation by improved collaboration between the professions.

Fig. 2. The main areas of the objectives.

Every year 21 students (7 from every country) will be selected to participate in SHE study. The selection process of the beneficiaries to be selected to participate in the intensive programs will be done by the Local Organization Office (LOO) of each partner organization (see Fig. 3). The eligibility of the candidates will be decided by common agreement, following a selection procedure settled by the consortium. The application will mainly contain an application form, a CV, a motivation letter, transcript of records and student certificate.

To meet the selection criteria established by SHE, evaluation standards will encompass the candidate's academic performance, prior mobility experience and experience in the host nation, among others. The student selection process and funding allocation will be equitable, transparent, consistent and documented, accessible to all stakeholders involved in the selection procedure. In order to help integrating the students facing economic obstacles, we will give prioritized access to 6 students (2 from each country), who fall into the category "Social Aid

Fig. 3. Selection of the students and a class in the installations of the hospital.

Scholarships". The LOO should inform the potential candidates, through brochures and information meetings and provide help and advice to candidates to set up their application.

2.2.2. Second objective: social inclusion (SI)

Regarding the social inclusion, the study SHE will:

- provides access to training for students in skills that are specially within hospitals
- provides access to information that is difficult to find outside the hospital environment, is scarce and expensive

All the teaching materials were open and free to anyone interested, regardless of the status or financial situation.

2.2.3. Third objective: innovative practices in a digital era (IPDE)

a) SHE offers innovative teaching methods and digital learning materials and tools (e-learning platforms, workshops, live streaming, etc.). All transmission, information, manual and learning materials will be open and free of charge for anyone interested, regardless of their status or financial situation.
b) Free access to a systematically updated book with the latest findings in sanitary engineering will help those interested to develop their knowledge and skills.
c) SHE promotes more efficient management of the operation, maintenance and safety of hospitals, their engineering installation, equipment and buildings.
d) The promotion of the latest methods in healthcare engineering through the creation of an easy-to-read online platform that can facilitate access to the latest research and new discoveries in healthcare engineering for anyone interested.
e) Employ the strategic use of new technologies in teaching/training activities using a tele-engineering approach to create an innovative best practice environment in the form of a platform where students can experience health engineering procedures. These procedures will be accompanied by specialist feedback.
f) The simulation and research group created by the consortium after the duration of the study will help SHE to maintain its objectives and activities even after the end of the study, which will ensure the continuation of high quality skills development for many generations to come.

Our main target group are the students. Through SHE studies we will easily facilitate a close connection between 3 universities, 3 hospitals and one company, which will benefit from each other's experience, transferring know-how available in one single country; we will centralize the most relevant information with the latest techniques on the e-platform, adaptable to the different users according to their needs for information.

2.3. Indicators

The organizational outcomes encompass the updating of curriculum and the allocation of resources for training in healthcare engineering. Moreover, novel concepts have been formulated to improve education in this domain, in conjunction with the incorporation of blended learning methodologies in practical teaching and training endeavors. This program promotes enhanced connectivity and international collaboration among European hospitals and universities focused on healthcare engineering, while offering complimentary access to systematically updated information.

The results at the individual level for each participant include the ability to engage in the complex processes of repair and maintenance within a real practice setting, allowing them to make real-time decisions on-site. Participants are also anticipated to develop basic competencies in solving healthcare engineering challenges and delivering effective solutions. Additionally, they will gain experience in using digital tools as part of the learning process.

The indicators that were used to achieve the objectives of this study were as follows:

a) quality control comments by external and internal experts.
b) qualitative evaluation feedback from participants (through questionnaires and focus groups).
c) structured web-based database.
d) report with recommendations with learning outcomes.
e) a health engineering manual, with real and easy-to-apply solutions.
f) a training, teaching and learning methodology.
g) weekly update of the electronic platform where the achievements of each participant are included, in order to promote competitiveness and creativity among new engineers.

2.4. Methodology

To systematically address the multi-faceted aspect of the project, the methodology presented in the figure below (see Fig. 4) was developed and it mainly consists of seven phases. The initial phase employs a qualitative and quantitative mixed-method approach to foster and analyze the collaboration between universities and hospitals from Spain, Turkey and Romania. The methodology focuses on understanding the mechanisms of knowledge transfer, identifying best practices and evaluating the impact of the collaboration. The second phase refers to 3 universities and 3 hospitals, together with professors from the universities, hospital staff, including administrators, maintenance engineers and medical professionals and to the last, the students enrolled in health-

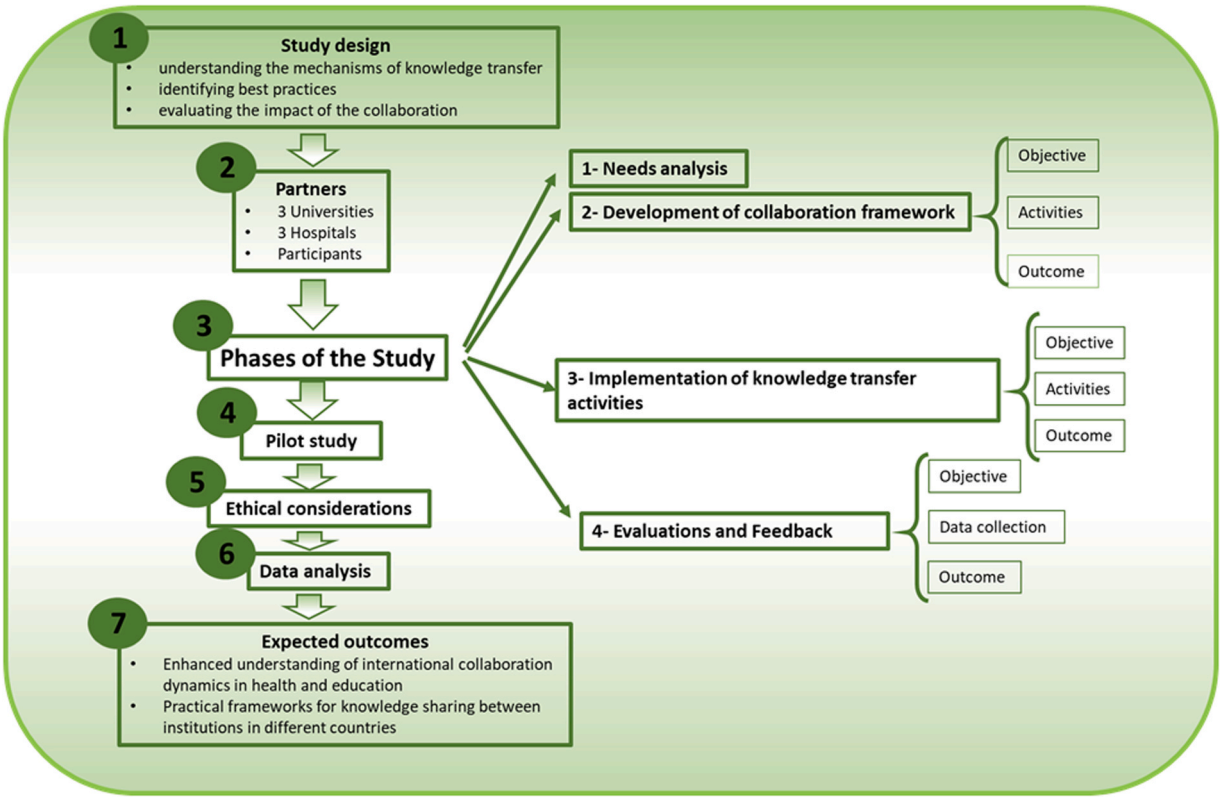

Fig. 4. The phases of the methodology.

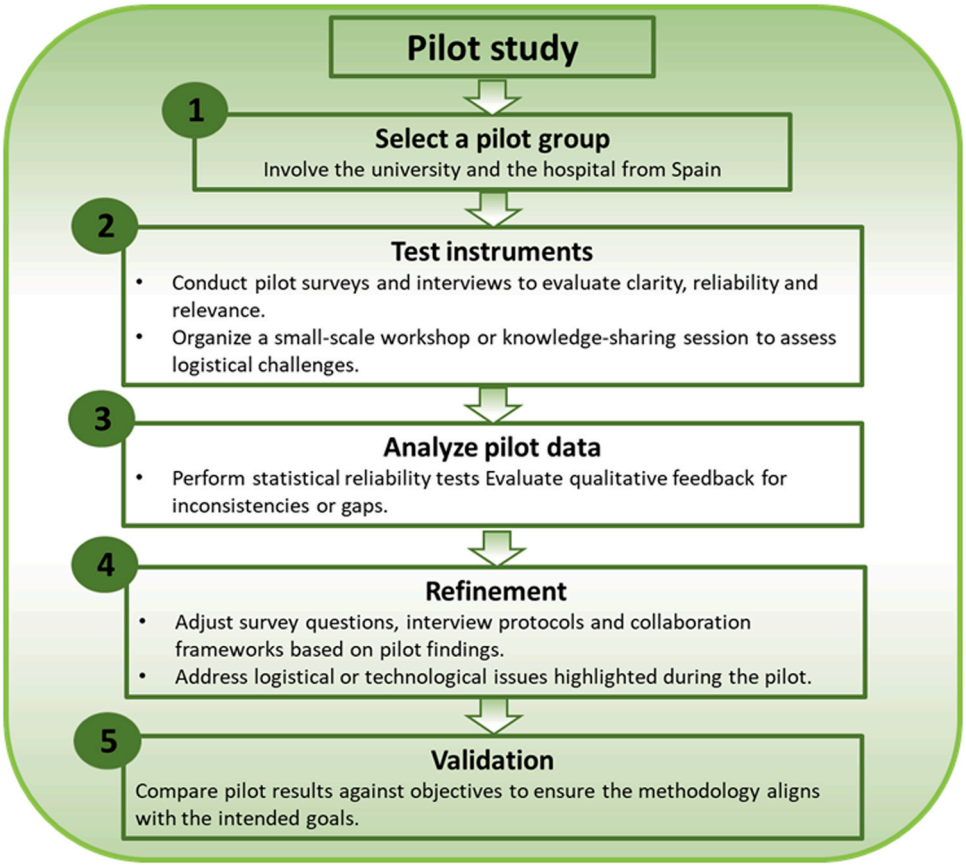

Fig. 5. Pilot study.

related program.

Phase 3 consisted of different sub-phases: 1) Needs Analysis, for identify existing resources and knowledge gaps in each participating institution. Online surveys targeting hospital and university staff and document review of existing practices and regulations in each country will be performed and as a result, a comprehensive baseline report detailing opportunities for knowledge transfer will be obtained. 2) It has as objective establish the structure for collaboration, including key areas for knowledge sharing, communication protocols and training methodologies. A standardized framework and toolkits for knowledge transfer will be obtained. 3) Conduct knowledge-sharing sessions and practical training by on-site workshops in each country, focusing on specialized topics like IoT in healthcare and hospital maintenance engineering. 4) Assess the effectiveness of the collaboration and refine practices having as a result a final report and recommendations for a sustainable international collaboration.

Phase 4, the Pilot study, see Fig. 5, has the objective to validate data collection instruments, detect weaknesses in methodology and ensure the feasibility of the study and is composed by five steps.

Phase 5 is focus on ethical consideration and consists of obtaining informed consent from all participants, ensuring data confidentiality following European, national and local regulations. Is very important secure ethical approval from institutional review boards of all participating universities and hospitals.

Phase 6, Data analysis consists of statistical analysis of survey results using tools like SPSS for quantitative data and NVivo for workshops feedback qualitative data.

Phase 7, expected outcomes, is detailed in the Fig. 4. By incorporating the pilot study, this methodology ensures that the study is both robust and adaptable, capable of delivering meaningful insights into international collaboration between universities and hospitals.

3. Impact

At the local and regional level, the SHEng project is anticipated to have a substantial impact on the internationalization process of the region (see Fig. 6). Specifically, other local and regional organisations are expected to benefit significantly from the experience and results of the project. The healthcare engineering field is likely to benefit the most, as institutes and organization in this field will have the opportunity to develop academic, teaching and training programs with diverse approaches. This approach will help combat academic inbreeding and enable the healthcare engineering field to develop based on the methodologies of the SHEng project. Consequently, the impact of the project will be particularly profound on the healthcare engineering field in the region.

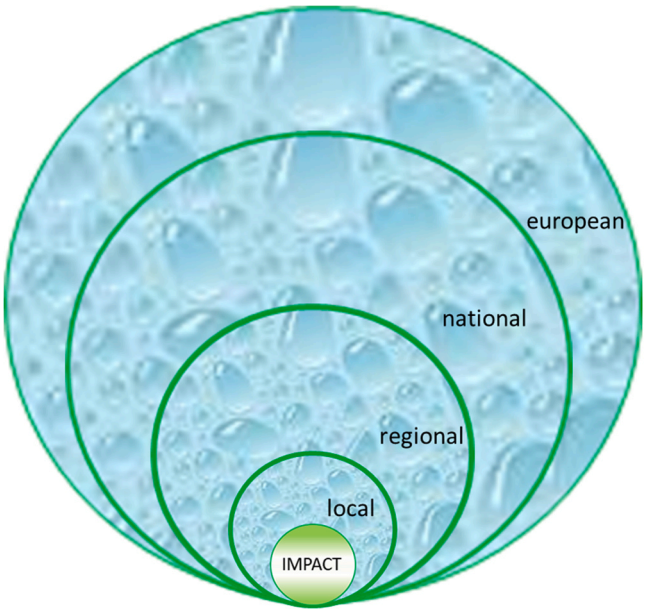

Fig. 6. The levels of impact.

At the national level, other universities and healthcare systems in the country can adopt the methodology of the SHEng project and work together to formulate new methods to prevent and combat different engineering problems. This approach will facilitate the transfer of cooperation information into knowledge and knowledge into results, which is a reliable process necessary at the inter-program level. The project's impact on doctors and patients will be apparent in easier and shorter time installations maintenance through the effective application of the project's results. Additionally, the promotion of European values and social code will enhance the understanding that national borders should not limit cooperation at an international level and expertise transfer can help achieve optimal results.

At the European level, the SHE project aims to reduce duplication of research effort, promote the effective use of resources and increase the impact of healthcare technology in the field of engineering. Specifically, the project will focus on describing technology, safety issues and relative effectiveness, as some data seem more transferable across the consortium. The desired impact of the project is primarily to contribute to developments in the field of healthcare, facilitate the industrial application of new knowledge and research findings and develop high-quality, relevant competencies of students suitable for the labor market. The project will serve as a solid bridge for scientific collaboration between Eastern and Western European countries and institutions.

In summary, the SHEng project's potential impact will be significant and distributed unevenly among participating organisations. The project's impact on each participating organisation will depend on the organisation's area of specialisation and the extent to which it can adopt the project's methodology. Additionally, the project will benefit other groups and organisations at local, regional, national and European levels and the extent of their potential benefits will vary based on their level of involvement in the project.

4. Discussion

The analysis of the pilot study aimed at validating data collection tools, identifying methodological shortcomings and assessing the study's feasibility. The pilot study included participants from Las Palmas de Gran Canaria University (7 students and 7 academic staff) and 4 persons from Universitary Hospital Dr. Negrin from Spain, guaranteeing a representative balance of academic and professional partners. The results are classified as quantitative and qualitative data.

The validation of data collections tools was made by surveys and interviews. At surveys the completion rate was 100 % (all the 18 participants) and the Cronbach́s alpha was 0.85 indicating a strong reliability. 48 % of the questions were rated as "Very clear" and 27 % as "Clear" and 25 % necessitated additional clarification or rephrasing. The qualitative feedback was: 1) Students perceived the technical terminology in 4 questions as confusing, 2) Professors observed repetition in inquiries concerning technological issues and 3) Hospital personnel valued the pragmatic inquiries but demanded more information. The interviews were somewhat larger (20 minutes) and therefore the number of participants was lower (2 professors, 4 students and 1 member of hospital staff. Interviewees emphasized the extensive range of questions, which occasionally resulted in repetitions. Hospital personnel underlined the necessity for more specific inquiries concerning IoT and automation obstacles. An agreement rate of 88 % was obtained, demonstrating significant concordance among reviewers.

At small-scale workshop have participated 7 students, 2 professors and 1 hospital staff and the duration of it was 4 hours (2 hours of theoretical presentations and 2 hours of practical sessions). At the end of the workshop, the students indicated challenges in comprehending

sophisticated IoT demos owing to insufficient prior exposure. Academics recommended enhanced congruence between theoretical frameworks and practical implementations and the hospital personnel valued the partnership but identified scheduling issues as an impediment to complete engagement. Minor delays in establishing IoT-based simulations attributed to inadequate preliminary testing were detected. No significant interruptions occurred; nevertheless, enhanced coordination between academic and hospital schedules was advised. 93 % of pilot study participants recognized the study strategy as attainable and the workshop activities along with instrument consistency validated the rigorousness of the methodology.

One of the weakness in the study was that even the surveys and interviews indicated accuracy and relevance, it is needed improvement in solving technical difficulties and repetition. The workshop approach was effective; nonetheless, it necessitated improved preparatory materials for students and a more coordinated timetable for participants. The data collection tools were substantial but need improvement to remove redundancy and solve deficiencies in basic knowledge and emerging subjects such as cybersecurity. Improvements increased the visibility, significance and efficiency of data collection tools and logistical arrangements. Professors underscored the scholarly significance of synchronizing pedagogy with state-of-the-art IoT innovations and the hospital personnel emphasized the practicality of expanding the system to encompass additional hospitals and universities.

5. Conclusions

SHE is an evolving idea that depends on the integration of diverse engineering principles and advanced technological breakthroughs relevant to healthcare. The demand for smart healthcare engineers is expected to increase, necessitating the training of qualified engineers. This research aims to present a methodology for transnational workshops in smart healthcare engineering education. Students gained new skills as well as expertise in emerging technologies critical to smart healthcare through the course's core topics.

Collaborative interdisciplinary work increases creativity in work groups, as well as interpersonal relationships between new engineers, developing fully trained professionals to be able to develop any activity within smart healthcare maintenance. It also prepares them to effectively address complex, multidimensional health care challenges.

CRediT authorship contribution statement

Luis Fernando Talavera Martin: Writing – original draft, Validation, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Julia Mirza-Rosca:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Conceptualization. **Ioan Fatu:** Validation, Supervision, Resources, Project administration, Formal analysis, Data curation, Conceptualization. **Mircea Horia Tierean:** Supervision, Project administration, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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