INCLUDING ELEMENTS OF BIOMEDICAL & CLINICAL ENGINEERING IN THE MEDICAL PHYSICS MSc CURRICULUM

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Abstract

The paper describes various educational activities where Biomedical & Clinical Engineering topics have been successfully included in the medical physics MSc curriculum. Examples are shown from various international projects, the curricula of the MSc in the University of Plovdiv, King's College London and ICTP and the University of Trieste. The feedback from the medical physics students shows very high appreciation of these activities (usually between 80 and 100 %). Further, examples are given about including such engineering elements in the Encyclopaedia of Medical Physics and the new sequel of IUPESM Workshops dedicated to collaboration between medical physicists and biomedical & clinical engineers. These collaborative examples are very useful for broadening the horizon of medical physicists about the numerous medical devices in a hospital. These are especially useful in Low-and Middle Income (LMI) countries, where the workforce of both professional occupations is often not sufficient to cover both clinical activities and equipment management.

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Keywords- **medical physics education, biomedical engineering education, collaboration between medical physicists and biomedical & clinical engineers.**,

I. INTRODUCTION

From the beginning of the establishment of professional societies in medical physics (MP) and biomedical engineering (BME), it was obvious that the specialists with these occupations collaborate closely in most healthcare institutions. Thus, in a number of countries medical physicists and biomedical engineers formed joint societies. It was natural to aim also at collaboration in the field of education. This paper presents very successful examples in this field. Additionally, inclusion of some BME elements in the curriculum of MP programs, contributes to better understanding the complex medical imaging and radiotherapy equipment. This also supports the collaboration between medical physicists and biomedical engineers.

This process is especially important in Low-and Middle Income (LMI) countries, where very few hospitals have dedicated team of clinical engineers (CE) handling all processes from the life cycle of a medical device.

Having basic understanding of the main principles of various types of medical equipment is very important for broadening the horizon of medical physicists about the various medical devices in a hospital. On the one side this is a very important moment of understanding the role of medical imaging equipment, radiotherapy equipment and other important medical devices in the technical park of a hospital. On the other side this is an important moment of understanding the specific steps in acquisition and maintenance of medical equipment – an area where medical physicists normally collaborate with clinical engineers.

II. INTRODUCING BME ELEMENTS IN THE TRADITIONAL MEDICAL PHYSICS MSc MODULES

Traditionally medical physicists work with equipment in medical imaging and radiotherapy. This equipment is the most complex in a hospital and should not be regarded as a "black box". Understanding the main elements inside the "black box" is very important also for the activities related to Quality Control of these very complex pieces of equipment.

When the Curriculum of the MSc in Medical Radiation Physics was developed in the project ERM (introduced in Plovdiv, Bulgaria during 1997), all specialized modules addressed both the physics and the engineering principles of the equipment [1,2] – the module names reflect this:

- Physics and Equipment of X-ray Diagnostic Radiology;
- Physics and Equipment of Nuclear Medicine;
- Physics and Equipment of Radiotherapy.
- Physics and Equipment of Ultrasound, MRI and Lasers in medicine;

These elements were found very useful by the students. The feedback results from 1998 and 1999 showed 100% student satisfaction. Based on this, modules with similar content and structure were introduced also in the curriculum of other medical physics MSc programs, developed with the support of the experience from the MSc in Plovdiv [2,3].

In a similar way engineering elements were introduced also in the Emerald e-learning materials [4,5] supporting medical physics training (**www.emerald2.eu**) – Fig.1. These materials were fully introduced at the teaching program of the ICTP College on Medical Physics in 1999. Following this the Emerald e-learning materials were given free to all College students. During the following years these e-materials formed the backbone of the Quality Control checks in most LMI countries. The use of elements of these materials continues even today in some countries (over 20 years since their introduction).

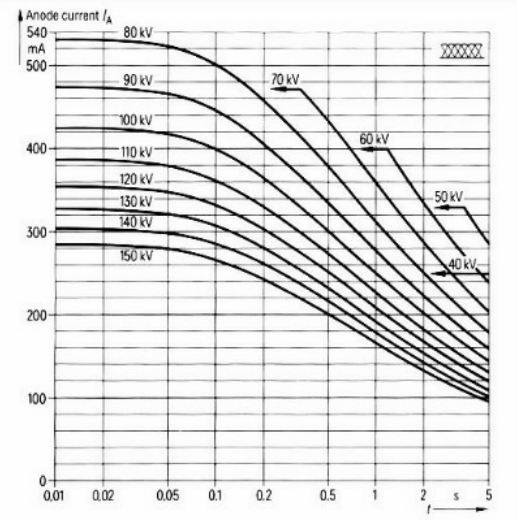

Fig.1 Typical engineering diagram of the function of an X-ray tube – example from the EMERALD medical physics e-learning training materials.

In 2001 this approach was also introduced at the MSc Medical Engineering and Physics at King's College London and is now used for over 20 years. Specific practicals were introduced in the medical imaging MSc modules, discussing not only the variation of some image quality parameters, but also the potential engineering reasons for this. Further medical physics students had discussions with industry engineers and visits to some manufacturers of imaging and radiotherapy equipment. The feedback collected was very positive.

Medical imaging practicals based on discussing problems with medical imaging equipment were introduced also at the ICTP College and were highly appreciated by the students. A Feedback Questionnaire with these students conducted in 2002 showed 100% approval of including engineering elements in their teaching program. These combined with use of e-learning showed significant increase of students' knowledge before/after the College (Fig.2 stats based on 60 students) [6].

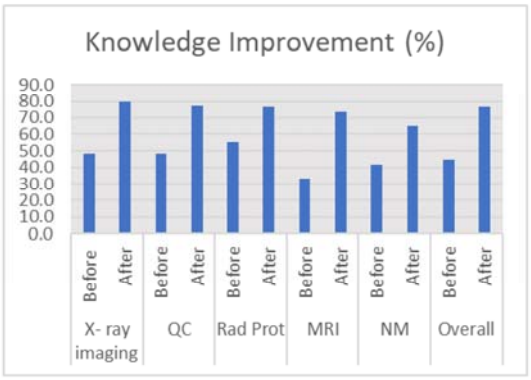

Fig.2 Improvement the % of student knowledge before and after the ICTP College in 2012 (self-assessment)

Additionally, in these questionnaires many students expressed desire to have some understanding of preparation of specifications and basic knowledge of maintenance and servicing of equipment, as in the LMI countries they are often without support from local service engineers and have to be able to better communicate both with the clinical engineers from nearby large hospitals and with the representatives of the equipment manufacturers.

While developing of basic Clinical engineering lectures for medical physicists required more time (and we shall describe it below), this feedback revealed the need of medical physicists to have a broader view of the medical equipment in a hospital.

III. INCLUDING SEPARATE MODULES ABOUT THE VARIOUS TYPES OF MEDICAL EQUIPMENT IN THE MEDICAL PHYSICS MSc CURRICULUM

In 2002 a new module was included in the set of foundation/core modules of the MSc on Medical Engineering and Physics (MEP) at King's College London - "Introduction to Medical Technology" [7]. The main parts of the module included elements grouped in the following fields:

A. The technology of medical imaging;
B. Application of radiation to therapy;
C. Artificial support systems;
D. The technology of physiological investigation;
E. Basis of hospital safety;
F. Quality and IT in healthcare.

The module (led by S Tabakov) was built as the forerunner for all MSc studies and was presented as a block module at the beginning of the academic year. Its aim was to introduce

students to the concepts and application of a wide range of technology in healthcare (used for diagnosis, therapy and management). The module provided the students with an understanding of the physical and physiological principles, together with engineering design, which underlies the specific medical equipment. It was also introducing them to the concepts of safe working practice through identification of hazards and methods for their reduction.

The MSc MEP was designed to have common foundation/core modules for medical physicists and biomedical engineers, each of the two groups of students later studying separate specialist modules for MP or BME.

The Introduction to Medical Technology foundation/core module was designed with about 30 hours lectures and related practicals. The results of the 2012 Questionnaire from 32 medical physics students and 14 clinical engineering students showed that MP students mark the usefulness of the module with an average of 86%, while CE students mark it with 78%. These marks remain similar in later years – e.g.: in 2014 the mark for MP students was 80% and for CE students was 83%; in 2016 the mark for MP students was 88% and for CE students was 80%.

IV. INCLUDING ELEMENTS OF MEDICAL EQUIPMENT MANAGEMENT IN THE MEDICAL PHYSICS MSc CURRICULUM

In 2003 the MSc MEP at King's College London introduced a new specialist module for clinical engineers – "Management of Medical Equipment" [7]. The module (led by C Roberts and K Ison). The aim of the module was to provide students with an insight into the problems and challenges of managing medical equipment within a healthcare system; to develop an awareness of the business process; to increase awareness of how maintenance of equipment is influenced by its design. The main parts of the module included elements grouped in the following fields:

A.Healthcare organisation and the role of clinical engineering;

B. Equipment specification and procurement;

C. Equipment management;

D. Quality systems in equipment management;

E. Safety in the clinical environment;

F. Business development (this part included coursework requiring the students to develop a business case for the operation of an equipment management service).

This specialised module included 30 hours lectures and practicals and was optional for those students who had decided to follow the path of clinical engineering. The module was left open for all students and from the beginning it attracted students from other BME sub-specialities (such as Rehabilitation Engineering). Surprisingly students from the medical physics specialisation attended a number of lectures in this module and during the next year there were foreign students in medical physics who had opted to pay for attending the full module. Their feedback showed both interest on the subject and lack of background knowledge.

In 2011 the UK NHS Modernising Scientific Careers framework included in the MSc curriculum in both themes "Medical Physics" and "Clinical Engineering" significant part of the elements of the module "Introduction to Medical Technology". This formed part of a new core module "Introduction to Medical Physics and Clinical Engineering". This module aimed to give a broad view to all students about medical equipment in healthcare. The new module also included simplified elements of the specialist module "Management of Medical Equipment". The syllabus of this module was designed to be used by all students in England, aiming at training and certification either as medical physicists or clinical engineers.

In 2009 the materials for the module "Management of Medical Equipment" were included in a textbook project (led by K Wislon, K Ison and S Tabakov) [8]. The textbook "Medical Equipment Management" was published in 2013 (see a review of the book further in this MPI issue).

V. INCLUDING MEDICAL EQUIPMENT MANAGEMENT IN THE CURRICULUM OF THE MSc IN MEDICAL PHYSICS AT ICTP AND THE UNIVERCITY OF TRIESTE

The unique College on Medical Physics at ICTP, Trieste, has been described in several issues of the MPI Journal as a vital educational activity for most medical physicists from the LMI countries. After 2002 the College teaching programme always included engineering elements in the typical medical physics lectures. These attracted constant high appreciation in all students' Questionnaires.

From 2006 the College introduced specific lectures and discussions about the development of medical physics MSc curriculum. These were very important for the establishment of new Medical Physics MSc programmes in various LMI countries. In the course of several years the answers from the Questionnaires (and the following discussion with students) underlined the need of additional foundation knowledge in medical equipment management, what would allow medical physicists in small countries to communicate better with their clinical engineering colleagues [9].

In 2014 a specific MSc in Medical Physics was established in Trieste, Italy – a collaboration between the ICTP and the University of Trieste, supported by the IAEA, IOMP and the Association of Medical Physicists in Italy. This MSc (led by R Padovani and R Longo) is specifically orientated to support

students from LMI countries. It is in English and takes 2 years (the second year being dedicated mainly to Hospital training and MSc project). Each year there are hundreds of applications from LMI countries for about 20-40 places.

The results of the Questionnaire (completed by 41 students mostly from Low-income countries) showed their collaboration with the local clinical engineers and the need of basic knowledge on this subject. Fig.3 shows their answers to the question about the local hospital management organisation. These answers revealed that in about half of the local hospitals in their countries there are no Departments of Clinical Engineering. Additionally, all students expressed need to know better the equipment management process in order to communicate better either with the clinical engineers or with the manufacturer's engineers dealing with equipment maintenance [10].

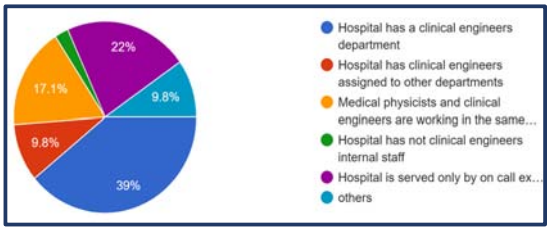

Fig.3 Results from the Questionnaire (from 41 students from 18 LMI countries) about the equipment management in their local hospitals

After the first couple of years, the MSc program was enriched with a module on Equipment Management. The module was based on the structure of the book "Medical Equipment Management" and introduced the students to basic concepts of equipment management in a hospital, specifically orientated to radiological equipment (imaging and radiotherapy).

The students' answers to a Questionnaire in 2019 showed that about 36% of the students think that they have sufficiently understood the subject and similarly 36% think that they cannot understand it. The remaining 38% think that they shall not be involved in the process of management of medical equipment (this corresponds well with Fig.2, where 39% of the LMI students work in hospitals with existing Departments of Clinical Engineering).

In parallel with the MSc curriculum, the ICTP College (which takes 3 weeks) included specific lectures on preparation of Specifications for Radiological equipment and on Basis of Organisation of Radiological Equipment Maintenance. The College in 2022 included these topics within the overall focus of the College –Medical Physics Capacity Building in LMI countries (see in this MPI issue a separate paper about the ICTP College 2022).

VI. THE ENCYCLOPAEDIA OF MEDICAL PHYSICS AS AN EDUCATIONAL REFERENCE, ENRICHED WITH ENGINEERING ELEMENTS

The success of introducing engineering elements in the medical physics curriculum led to the invitation of IFMBE colleagues to join the team of the EMITEL project (2006-2009, coordinated by S Tabakov), developing the first Encyclopaedia of Medical Physics – an open online reference to all colleagues, used today by thousand of colleagues each month through its web site: **www.emitel2.eu**

The engineering elements in the Encyclopaedia were supported with hundreds of specially made diagrams and block diagrams of radiological equipment. The first issue of the Encyclopaedia was released online in 2010 and on paper in 2012.

The second edition of the Encyclopaedia included about 650 new terms [11]. All previous emphasis of avoiding the "black box" presentation of the radiological equipment was kept and additional elements were added in the General part of the Encyclopaedia (led by S Tabakov and M Stoeva). For the first time basic terms of Clinical engineering were introduced (adapted for medical physicists). This sub-part of the Encyclopaedia was led by E Iadanza. This edition was also supported with numerous diagrams – see examples on Fig.4 and Fig.5.

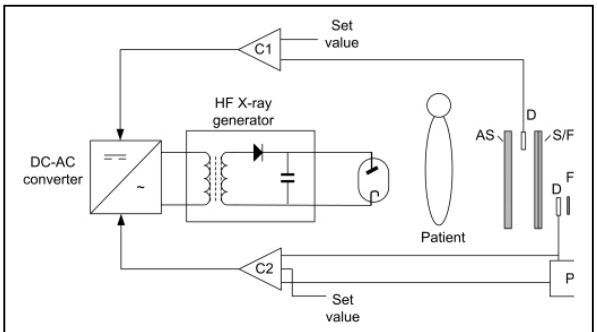

Fig.4 Block diagram of Automatic exposure control system - *from Encyclopaedia of Medical Physics II Edition - article: Automatic exposure control system*

The main aim of this Encyclopaedia is educational – supporting the MSc-level courses as an open online resource. The diagrams and block diagrams have already found place in a number of MSc lectures on the subject. The second edition of the Encyclopaedia was released on paper in 2021.

In parallel with the Encyclopaedia Update a textbook was developed "Introduction to Medical Physics", aiming to give a broad view to a medical physicist about the various sub-fields in the profession. This was necessary as the volume of the knowledge in the profession (respectively - the MSc curriculum) was constantly being enlarging with many new methods and equipment, while the hours in the typical MSc curriculum remain the same). This created the necessity for many medical physics MSc programmes to cut significantly the general parts of their curriculum and to introduce early narrow specialisation. The textbook aimed to add information about the subjects outside the narrow specialisation, again enriched with some engineering elements (see the review of this book in the MPI issue from 2022 – vol.10, No.1). The book was also aimed at the emerging new BSc programmes on medical physics and biomedical engineering. The textbook was published by CRC Press (both on paper and as e-book) in 2022 [12].

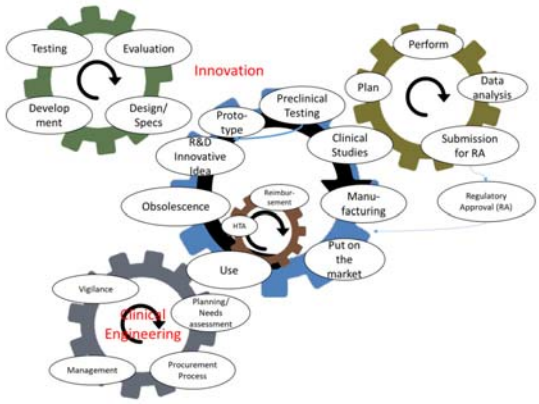

Fig.5 A diagram illustrating the Life cycle of an equipment - *from Encyclopaedia of Medical Physics II Edition - article: Life cycle of equipment*

VII. IUPESM WORKSHOPS FOR COLLABORATION BETWEEN MEDICAL PHYSICISTS AND BIOMEDICAL/CLINICAL ENGINEERS

In order to strengthen the links between medical physicists and biomedical & clinical engineers IUPESM introduced in 2018 a new activity – Collaborative Workshops (led by M Stoeva and KP Lin).

The first such activity was organised in Taipei, as a satellite to the International Conference on Biomedical and Health Informatics (ICBHI 2019). It naturally focussed on collaborative educational activities. The same topic was highlighted at the second such Workshop in Rome, satellite to the International Clinical Engineering and Health Technology Management Congress (ICEHTMC 2019) – Fig.6. Other such events followed either at events under the aegis of IFMBE, or IOMP, or IUPESM [13, 14]. Such Workshops were organised also during the World Congress

Fig.6 Organisers and lecturers (including the co-authors of this paper) at the IUPESM Workshop on collaboration between medical physicists and biomedical & clinical engineers, Rome, 2019.

on Medical Physics and Biomedical Engineering (Singapore, 2022), the Asia-Oceania Congress on Medical Physics (Taipei, 2022) and during 2022 IOMP hosted a Webinar during the Day of Clinical Engineering (Co-organised by M Stoeva and E Iadanza).

All the collaborative activities between medical physicists and biomedical & clinical engineers support not only exchange of ideas and potential collaborative research, but also the enrichment of the educational programmes. The latter are especially important for LMI countries, where the currently existing workforce needs additional knowledge to support both the clinical activities and the management of medical equipment

VIII. CONCLUSION

The introduction of engineering elements in the MSc curricula for medical physicists proved to be beneficial for the understanding of the enormous variety of medical devices in a hospital. This broadening of their horizon received the high approval of most students. Further, the understanding of the main engineering principles of equipment used in medical imaging and radiotherapy was found to be very useful for the understanding and analysis of various Quality control tests.

The basic understanding of equipment management principles by medical physicists supports their collaboration and communication with the clinical engineers. This is especially important during the process of procurement of new such equipment and arranging its maintenance. In LMI countries, where only small number of hospitals have clinical

engineering staff this knowledge is vital for the exploitation of the imaging and radiotherapy equipment.

The enormous speed of development and implementation of various medical devices in healthcare, and the limited number of academic hours in an MSc programme leads often to an early narrow specialization of medical physicists. The natural expansion of medical physics education is in the direction of including basic and core topics (of both medical physics and biomedical engineering) at the rapidly emerging new BSc programs on the subject. This process is already gaining speed and the successful collaboration between medical physicists and biomedical engineers will be very important for the preparation of further foundation topics for the future BSc programs in these fields.

The international success of the collaboration between medical physicists and biomedical engineers through IUPESM led to the international recognition of both scientific fields as unique parts of physics and engineering applied to medicine. Further IUPESM led the international recognition of both professional occupations (medical physicists and biomedical engineer) in the ISCO-08 (the International Standard Classification of Occupations). It is only natural that the increased collaboration in the field of education will continue to expand this success of the development, clinical implementation and management of medical devices, which are now an indispensable part of contemporary healthcare.

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