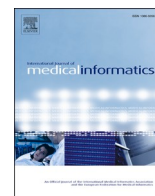




Contents lists available at ScienceDirect

International Journal of Medical Informatics

journal homepage: www.elsevier.com/locate/ijmedinf

Bioengineering and medical informatics education in MD programs: perspectives from three Italian experiences

Riccardo Bellazzi^a, Maurizio Cecconi^{b,c}, Maria Laura Costantino^d, Pierangelo Veltri^{e,f,*}

^a Department of Electrical, Computer and Biomedical Engineering, University of Pavia, Italy

^b Department of Biomedical Sciences, Anesthesiology and Intensive Care, Humanitas University Pieve Emanuele, Milan, Italy

^c Anaesthesia and Intensive Care Medicine IRCCS Humanitas Research Hospital, Rozzano, Milan, Italy,

^d Department of Chemistry, Materials and Chemical Engineering "Giulio Natta", Politecnico di Milano, Milan, Italy

^e Department of Surgical and Medical Science, University Magna Graecia of Catanzaro, Catanzaro, Italy

^f Computer Science, Modeling, Electronics, and Systems Engineering (DIMES), University of Calabria, Rende, Italy

ARTICLE INFO

keywords:

Medicine and Technologies
Biomedical Engineering
Medical Informatics
Medical Education
MEDTEC
MEET
Medicina e Chirurgia TD

ABSTRACT

Background: Given the impact of bioengineering and medical informatics technologies in health care, the design and implementation of education programs able to combine medical curricula with a proper teaching on engineering and informatics is now of paramount importance. In Italy, this goal has to fit in with the existing higher education system, which is structured into Bachelor programs and Master programs. Medicine and Surgery programs, instead, are designed as a six-year single-cycle Degree Program in Medicine and Surgery which comprises both class attendance and hospital internship and training. This program allows students to become Medical Doctors (MD). The different organization of this University program makes it not easy to introduce further contents, namely hard science courses, in the educational program. Notwithstanding this, we present here some recent innovative programs aimed at widening MD curriculum by including biomedical engineering and informatics subjects. In particular, we will introduce three of them. Two are joint-degree programs, the first between Humanitas University and Politecnico di Milano (MEDTEC School), and the second between University of Calabria and University Magna Graecia of Catanzaro (Medicina e Chirurgia TD). The Third one is a Professional Master coupled with an MD degree, based on a joint program among Pavia University, Pisa University, the Institute of Advanced studies in Pavia and the Scuola Superiore S. Anna in Pisa (MEET).

Contribution: The paper provides a description of the fundamental design principles of the three above mentioned programs, and explores some aspects of the teaching modules, highlighting their positive aspects. In particular, we show how the three different programs allow students to enrich their knowledge by studying engineering subjects and innovative methods and technologies, as well as their applications to patient care.

Conclusions: The MEDTEC program is the first degree program at Italian and international scale which integrates medical and engineering subjects. In the following years, other programs were issued in Italy, defining similar education programs to couple a degree in medicine education with bioengineering and medical informatics, among which Medicina e Chirurgia TD and MEET. We believe the experiences described here in this paper represent the possibility of bridging the gap between medical and technological competencies.

1. Introduction

Nowadays the importance of strengthening the bioengineering and biomedical informatics knowledge of health professionals has been widely recognized. The pandemic has made it even more clear that a strong intertwining of medicine and engineering disciplines is a key

instrument to build a resilient health care system, capable of dealing with the local and global challenges. However, implementation of education programs requires careful design and tailoring to the specific higher education system.

In this paper, we will discuss different approaches and programs aimed at integrating medical and engineering subjects thus to widen

* Corresponding author.

E-mail addresses: riccardo.bellazzi@unipv.it (R. Bellazzi), maurizio.cecconi@hunimed.eu (M. Cecconi), marialaura.costantino@polimi.it (M.L. Costantino), veltri@unicz.it, pierangelo.veltri@unical.it (P. Veltri).

<https://doi.org/10.1016/j.ijmedinf.2023.105002>

Received 18 February 2022; Received in revised form 14 January 2023; Accepted 17 January 2023

Available online 27 January 2023

1386-5056/© 2023 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

medical doctor culture and knowledge. Of these, two are joint-degree programs jointly issued by Humanitas University and Politecnico di Milano (MEDTEC), and by University of Calabria and University Magna Graecia of Catanzaro (Medicina e Chirurgia TD), and one is a Professional Master coupled with the MD degree awarded by the University of Pisa, University of Pavia, University of Pisa, the Institute of Advanced studies in Pavia and the Scuola Superiore S. Anna in Pisa (MEET). The three programs share similar targets even if they have different modules and contents in terms of study plan. In the paper we discuss the three programs in separate sections.

The first Italian experience, started in 2019 as a joint degree in Medicine and Biomedical Engineering has been implemented in Milano. This program, called MEDTEC, and issued by Humanitas University in partnership with Politecnico di Milano, is taught in English. At the very end of the six-year program, students will be awarded the graduation in Medicine and Surgery by Humanitas University and also the bachelor degree in Biomedical Engineering by Politecnico di Milano.

The second and more recent joint degree, which began in 2021, is based on the cooperation between the Medical School of Magna Graecia University in Catanzaro and the University of Calabria. This program called "Medicina e Chirurgia TD" (Medicine and Surgery Digital Technologies), is a 6 year master degree in Medicine and Surgery comprising subjects of Digital Technology and is taught in Italian. The program allows students to obtain two degrees: one in medicine at the end of 6 years, and one bachelor 3-year in computer science applied to medicine by performing a little numbers of additional courses.

The third program is a Path of Excellence offered by University of Pavia, called *Medicine Enhanced by Engineering Technologies* or MEET program. It allows students to integrate standard MD subjects with engineering and informatics courses. As we will see in Section 5, the MEET program selects voluntary students after two years of MD training, and provides them with extracurricular courses. At the completion of the standard 6 year MD program, students will also obtain the MEET Professional Master.

The shared goal of these three programs as well as of other more recent programs allow students to learn, not only the most innovative methods and technologies, but also how to apply these approaches to patient care. In this context, the student also gains basic knowledge of health management, ethics and frontier medicine.

Outline. The paper is organized as follows. Section 2 reports relevant experiences on programs integrating Medicine and Engineer programs. Sections 3, 4 and 5 report the definition and structural information about classes and teaching of the three presented programs. Then, Section 6 contains a discussion on the differences between them and discusses possible future directions.

2. Running experiences

The necessity to widen medical education with technology topics started to be considered since the '70 s of the last century, considering the possibility for a medical doctor to apply for a PhD in other fields comprising biomedical engineering [1].

However, with the increasing use of advanced technologies in the hospitals and the widespread adoption of engineering methods, tools, and devices in medical practice, the need of formal technological education in the medical school has become compelling. The main challenge is to design programs that effectively educate clinicians and practitioners, while providing them with a strong background and deep understanding in engineering technologies [2,3]. This has raised a debate over the last twenty years; this debate has been in general related to the redesign of MD educational programs [4,5]. It is however over the last ten years that these discussions have started to be translated into real educational projects [6,7,8,9]. More recently, the widespread adoption of AI in image processing, 3D printing for surgery planning and medical simulation for education has accelerated this ongoing process [10,11]. In the world some other experiences offer a kind of joint education in

medicine and engineering/medical informatics, it is interesting to mention those that have similarities with the Italian scenario. University of Shanghai has started an integrated medical curriculum in the interdisciplinary field of medical engineering, with a profoundly revised organization of teaching and specialty education within the same program [11]. University of Galway offers a double degree program that provides students the chance to have a medical degree as well as a bachelor and/or master degree in Biomedical Engineering, within an 8-year program [12]. The University of Texas A&M's College of Engineering, College of Medicine and the Houston Methodist Hospital offer medical students the possibility of a double degree in biomedical engineering [13]. Similarly, Duke University and Singapore University offer a five-year medical program that can be followed by a master in engineering [14], framed in a unique path. The most similar program to the Italian ones has been issued in Israel at Technion University of Technology. This program offers a dual degree in medicine and biomedical Engineering that, after completion will award Medicine and Surgery degree and biomedical engineering bachelor degree [15]. This double program has a 9 years global duration. A different model is provided by the University of Florida, where it is possible to start a PhD program in Biomedical Engineering with a concurrent medical program, along a 7-year duration [16]. Finally, the University of Sidney offers a double bachelor program thus allowing students to gain one bachelor of science in Biomedical Engineering and one in Medical Science, before entering the medical school [17].

This large number of initiatives, with different implementation strategies, clearly show that the time is mature for educating a new generation of clinicians and practitioners, able to proficiently use technologies and collaborate to their effective design. It is therefore an obvious consequence that such educational programs will spread out in many countries according to local regulation constraints.

In the national and the international scenario, the Italian MEDTEC program, which is offered to international students, is the first initiative merging medical school and biomedical engineering profiles in such a unique 6-year program. Starting from this experience, at the time of we wrote this manuscript, other Italian Universities, such as University of Salento, University of Catanzaro and University of Calabria, Campus Biomedico in Rome, and University of Pavia initiative, have issued similar student programs.

3. Politecnico di Milano and Humanitas University Hospital

The first experience of a joint degree in medicine and biomedical engineering in Italy and Europe started thanks to the collaboration between Politecnico di Milano and Humanitas University, that are among the most internationally ranked engineering, and medical schools. Politecnico di Milano has a well-defined background in the design and use of artificial organs, bio-robotics, nanotechnologies as well as 3D printing and bio-prosthesis, while Humanitas University holds advanced and innovative approaches to medical subject teaching and research together with the use of advanced technological solutions to patient treatment. These elements are boosted by the close location and synergy with Humanitas Hospital. The joint degree focuses on enhancing the medical skills of MD students through the integration and acquisition of competences relevant to technology. It offers a multi-disciplinary approach by introducing biomedical engineering methodologies and technologies into medical education and training to foster integration between the two disciplines. An innovative approach to doctor-patient interaction is proposed to enhance the aware understanding of the use of technology and intelligent systems, including precision medicine, big data, artificial intelligence, data analysis, remote control and monitoring. The program entails: (i) a bio-medical engineering approach to basic scientific disciplines (e.g. maths, chemistry, physics, statistics, biomechanics, computer science etc.); (ii) subjects related to precision and regenerative medicine; (iii) application of technology and informatics to medicine through the integration of pre-clinical and clinical education

with advanced engineering subjects. These subjects are all merged in the medical doctor program.

This integrated six-year program allows the student to be awarded at the very end of the program both the degree in medicine and surgery by Humanitas University and the bachelor degree in biomedical Engineering by Politecnico di Milano. The presence at Humanitas University of laboratories and simulation centers allows the future physicians to strengthen their knowledge about the use of technologies in medical practice. The physician will thus be able to manage technologies and to apply an increasingly personalized medicine using highly complex technological systems for treatment, clinical evaluation and diagnosis. This new professional figure will be able to manage the present and future technologies that are more and more permeating the medical profession bringing to an increasingly application of personalized treatment by using complex technology and solutions. In order to increase the merging of the medical and engineering culture, MEDTEC students have classes at Politecnico di Milano during the first semesters of the first 3 years and the second at Humanitas University. Starting from the fourth year all attendance is at Humanitas University due to the clinical internship. Also co-teaching activities (biomedical engineering and medical professors) complete the application landscape together with seminars and/or internship offered by companies.

3.1. Training program

The course is based on the academic approach of Humanitas University and Politecnico di Milano, which involves the use of interactive methodologies (such as Research-based Learning, Problem-Based Learning, Problem Solving, Case Method and the portfolio of skills) to guarantee integration between the theoretical concepts learned in the lectures and the more practical and professional aspects necessary to promote and develop autonomous and critical thinking. The detailed study plan for MEDTEC program can be found at [18].

3.2. MEDTEC graduate

The first cohort of MEDTEC students will graduate in 2025. They will be able to apply to any specialization course in any medical and clinical areas (e.g., cardiology, neurology, surgery etc.) and/or to a PhD course (either in biomedical engineering or medicine) as well as to biomedical or pharma companies.

4. Medicine and digital technologies in Calabria

The “Medicina e Chirurgia TD” (standing for Medicine and Surgery Digital Technologies) is a six-year single-cycle Degree in Medicine, that started in 2021. It is a jointly program between the University of Catanzaro, which hosts a Medical School, and the University of Calabria, which hosts Computer Engineering and Pharmacology Schools. The innovation consists in introducing the study and application of a new digital technologies into a medical training program. Medical doctors will be able to use computer science skills to manage tasks related to health science, such as bioinformatics, health informatics, biomechanics.

The course allows students to obtain a 6-year medical degree and 3-year Computer Engineer bachelor. The course is a medical one, thus students after 6 years obtain a medical degree but classes include mathematical, physics and computer engineering basics necessary to enrich medical background through digital related topics. Moreover, students may obtain a 3-year computer science bachelor degree by attending a limited number of additional classes. The degree is jointly released by both universities. The first three years teaching classes are provided at University of Calabria Campus, while during latter three years students will attend classes at Univeristy Magna Graecia Campus.

4.1. Training program

The training is organized around clinically based knowledge, ICT and digital topics, clinical and surgical area. As for all medical program classes, human morphology, genetics and biological relates they perform studies during first three years. Solid foundations in the fields of chemistry, physics, mathematics and information technology are taught. Bioinformatics and biomedical applications are also part of the teaching classes, together with mathematics and statistics, chemistry and physics, cell biology, computational and tissue database management for medical science. In the latter three years, clinical and surgery science are treated, completed with clinical training activities that are performed in University of Catanzaro Medical Hospital. Classes are also characterized by innovative technologies for diagnosis, therapy and clinical applications. Medicine classes are enriched by bioengineering and health informatics classes such as telecommunications and Telemedicine, Health service planning and management, biomechanics, bioinformatics and health data management.

Students, once completed the 6 years, acquire competences regarding medical and clinical practice, as well as competences in ICT and biomedical applications. The detailed study plan for Medicina e Chirurgia TD can be found at [19].

4.2. Graduated students

In 2026 the first set of students in Medicina e Chirurgia TD will obtain the Medicine degree. The young medics will be able to use and design applications for technologies in all areas of clinical and medical applications. Managing data sources requires expertise in terms of data management and extraction tools. The application of new technologies such as telemedicine, or using wearable devices or using IoT technologies for clinicians may give new opportunities.

5. Medicine Enhanced by engineering technologies Master (MEET) – University of Pavia

The “Medicine Enhanced by Engineering Technologies” Path of Excellence (MEET) is implemented thanks to the collaboration between four universities: the University of Pavia, the University of Pisa, the Sant’Anna School of Advanced Studies in Pisa and the Institute for Advanced Studies (IUSS) in Pavia. It is designed for students enrolled in MD programs in Pavia and Pisa, with a path of excellence aimed at expanding the knowledge of medical students in the field of new engineering and informatics technologies and their growing impact on clinical, diagnostic and therapeutic practices. This integrative and interdisciplinary training program offers additional teaching in several topics comprising telemedicine, robotic surgery, artificial intelligence, prostheses, 3D printing, wearable sensors. The use of these new technologies in the medical field requires a proper understanding of their rationale, design principles and implementation aspects. The program is designed to teach not only the most innovative technologies and methods in the field of medical and bioengineering research, but also provide strategies to put into practice these approaches, with focus on improving patient care, innovate therapies and overall communication between doctor and patient also regarding technological aspects. In this context, the student will also acquire fundamental knowledge in the field of health management, and techno-ethics in medicine. At the end of the course, after obtaining the Degree in Medicine and Surgery, graduates will obtain, after the completion of a graduation thesis, the MEET Master, which will be issued jointly by the four participating universities. The main idea behind the MEET program is to add engineering content to the standard MD program, without major changes to the main “backbone” education of clinicians, but requiring extra effort from highly motivated students. All MEET classes are purposely designed for MD students, and the content is adapted to the main goal of improving basic knowledge and understanding of the taught topic. The final goal is

therefore to improve MDs' competence in engineering discipline rather than working on a profile that is at the same time the one of an MD and the one of an engineer.

5.1. Training program

The MEET program develops over 4 years, from the third to the sixth year of the course in Medicine and Surgery, and involves the acquisition of supernumerary education credits that comprise lectures and laboratory classes as well as as internship and the thesis preparation. The courses scheduled for the 1st and 2nd year of the MEET course are compulsory for all students. Starting from the third year, students will have to submit a study plan by selecting three courses from those proposed.

The overall study plan is designed to provide the fundamental building blocks of engineering technologies in the Common Path, integrated with more advanced content in the Elective courses. The study plan assumes that the students have already followed courses in Physics, Chemistry, Biochemistry, Statistics and epidemiology in the MD program. In the first year, first semester provides basic Math, computer programming and statistics courses. Then the bioengineering content is introduced starting from the second semester onward. Biomechanics, biomaterials, biomedical instrumentation, Medical Informatics, Signal and image processing, AI in medicine, 3D printing technologies represent the backbone of the course. Note that in the second year, the student has also to study topics related to ethical issues generated by introducing the new technologies in health care and in the fourth year the basics of health care organization. Finally, elective and advanced courses include telemedicine, bioinformatics, robotics (medical and rehabilitation), bioelectronics, radiomics and tissue engineering.

5.2. Future of the MEET students

The MEET program leads to a Master in Engineering Technologies. After completion of the MD program, therefore the students will have two degrees, a "Laurea Magistralis" in Medicine and Surgery, and a "Second level" Master. The MEET trained physicians will thus have additional knowledge and skills, and will also held a dual title that will strengthen their curriculum in the national and international context. At the present time the future prospects of the MD students looks positive as their qualification will open up a host of clinical and research opportunities; with the MEET program, such opportunities will be probably even greater.

6. Comparing the three experiences: New directions for new classes

Moving from similar premises, the three experiences present substantial differences in their implementation. MEDTEC proposes a close integration between medical and engineering education, thus leading to a joint degree at the end of the course. This implies a strong redesign of the medical curricula and the definition of an uncommon engineering profile. The overall plan of the program has been carefully defined from the beginning and the bioengineering content adapted to the needs of medical education. The University of Calabria and University of Catanzaro program follows MEDTEC, with the same type of implementation, but the technical content is more geared to ICT aspects than to bioengineering ones. A different approach is represented by the MEET master. In this case, the students follow a standard course of medicine, while adding "on top" extra curricular content in bioengineering that provides a Master in BioMedical Engineering technologies. This makes the program an addition to the standard MD courses that only a selected group of students may decide to follow. The loose integration between the two curricula allows for a flexible approach in adapting the content of the bioengineering courses to the needs of the medical school without awarding an engineering degree at the end of the program. MEET has

however the difficulty of adding extra hours to an already highly demanding program, like the medical school, and needs a careful planning and implementation.

The three models represent in Italy starting examples to design new similar activities. Moving from the consideration that MD education needs strengthening in engineering and informatics technologies, many other universities are considering initiatives along this path. The running experience that is accumulating with these three programs will be certainly beneficial both to redesign the existing ones and to drive the definition of novel curricula, with the final goal of providing the healthcare workforce needed by the current times.

7. Conclusion

In this paper we described three initiatives of teaching programs including medicine classes and technologies, exploring aspects of the teaching modules, highlighting their positive aspects. We reported the initiatives and we sketched similar cases in international scenario allowing students to learn engineering subjects and innovative methods and technologies to be include in a medicine degree.

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.

Acknowledgements

The authors are deeply grateful to all the colleagues from the involved universities who participated to the construction of these new kind of educational initiative.

References

- [1] W.J. Harrington, W.J. Whelan, B.J. Fogel, E.M. Papper, Alleviating the shortage of physicians: an accelerated md program for ph. d.'s in the biological, physical, and engineering sciences is underway, *Science* 172 (3988) (1971) 1109–1111.
- [2] B. Vidic, H.M. Weitlauf, Horizontal and vertical integration of academic disciplines in the medical school curriculum, *Clin. Anat.* 15 (3) (2002) 233–235.
- [3] Mieke Vandewaetere, Dominique Manhaeve, Bert Aertgeerts, Geraldine Clarebout, Jeroen J.G. Van Merriënboer, Ann Roex, 4c/id in medical education: how to design an educational program based on whole-task learning: Ameer guide no. 93, *Med. Teach.* 37(1) (2015) 4–20.
- [4] J.R. Frank, L.S. Snell, O. Ten Cate, E.S. Holmboe, C. Car-raccio, Susan R. Swing, Peter Harris, Nicholas J. Glasgow, Craig Campbell, Deepak Dath, et al., Competency-based medical education: theory to practice, *Med. Teach.* 32 (8) (2010) 638–645.
- [5] D. Fan, Holistic integrative medicine: toward a new era of medical advancement, *Front. Med.* 11 (1) (2017) 152–159.
- [6] S.B. Arja, S.B. Arja, R. M. Venkata, A. Nayakanti, P. Kottathveetil, Y. Acharya, Integrated curriculum and the change process in undergraduate medical education, *Med. Teach.* 40 (5) (2018) 437–442.
- [7] Lori DiPrete Brown, Towards defining interprofessional competencies for global health education: drawing on educational frameworks and the experience of the uw-madison global health institute, *J. Law Med. Ethics* 42 (S2) (2014) 32–37.
- [8] David G. Brauer, Kristi J. Ferguson, The integrated curriculum in medical education: Ameer guide no. 96, *Med. Teach.* 37(4) (2015) 312–322.
- [9] E. Brouwer, E. Driessen, N.H. Mamat, V.D. Nadarajah, K. Somodi, J. Frambach, Educating universal professionals or global physicians? a multi-centre study of international medical programmes design, *Med. Teacher* 42 (2) (2020) 221–227.
- [10] Xing Lei, A. Krupinski Elizabeth, Cai Jing, Artificial intelligence will soon change the landscape of medical physics research and practice, *Med. Phys.* 45(5) (2018) 17917–1793.
- [11] P. Zhang, L. Ji, G. Zhou, X. Yao, A commentary on the practice of integrated medical curriculum in the interdisciplinary field of medical engineering, *Ann. Med.* 54 (1) (2022) 812–819.
- [12] University of Galway: Dual Medicine-Engineering Degree, 2022. <[https:// www.universityofgalway.ie/physicianeerdegree/#](https://www.universityofgalway.ie/physicianeerdegree/#)>.
- [13] University of Texas A&M: School of Engineering and Medicine, 2022. <[https:// enmed.tamu.edu/](https://enmed.tamu.edu/)>.
- [14] Duke University: MD+Master of Engineering Dual Degree, 2022. <[https:// bme.duke.edu/masters/degrees/md-meng](https://bme.duke.edu/masters/degrees/md-meng)>.

- [15] Technion University: MD and BSc – Dual Degree in Biomedical Engineering and Medicine, 2022. <<https://www.usf.edu/engineering/chbme/documents/biomedical-eng-medicine-dual-degree-4.pdf>>.
- [16] University of South Florida: MD+PhD in biomedical engineering, 2022. <<https://www.usf.edu/engineering/chbme/documents/biomedical-eng-medicine-dual-degree-4.pdf>>.
- [17] University of Sidney: Bachelor of Engineering Honours (Biomedical) and Bachelor of Science (Medical Science), 2022. <<https://www.sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical-and-bachelor-of-science-medical-science.html>>.
- [18] Politecnico di Milano, Humanitas Joint Laurea: "Program, and Class organization for MEDTEC". <<https://www.hunimed.eu/it/course/medtec/struttura-del-programma/>>.
- [19] University of Calabria and University of Catanzaro Joint program: Program for Laurea in Medicina Digitale, 2022. <https://www2.unical.it/portale/portalmidia/2022-01/Piano%20di%20Studio%20MTD%202021_22.pdf>.