Medicine and BioHealth Journal

Journal homepage: https://ojs.omgfzc.com/index.php/MBJ

(Original Article)

Physics for Medical Colleges: Proposing an Extended Syllabus

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Article Info

Article History:
Submitted/Received 12 June 2024
Revised in revised format 17 July 2024
Accepted 24 July 2024
Available Online 10 August 2024
Publication Date 10 September 2024

Keyword:
Physics in medicine
premedical; preclinical
clinical education
Medical science

Cite this article: *Omer, H., Toufig, H. Abuelhia, A., M Twfieg (2024). Physics for Medical Colleges: Proposing an Extended Syllabus. Med. Biohealth. J. 1(1), 1-8.*

DOI: https://doi.org/10.70274/medbiohealth.2024.1.1.18

ISSN 3007-6374

ABSTRACT

Background: Physics has indeed revolutionized medical practice since the birth of medicine thousands of years ago. It provided us with a better understanding of our health problems through many diagnostic and treatment tools yet, many medical colleges do not fully implement physics as a core subject in their curricula. Physics is taught only as a freshman year subject, and many medical students feel obliged to take it without knowing its real benefits to their future careers. This is basically due to the lack of an appropriate course design, references, and the poor commissioning of physics in the medical field.

Objective: The aim of this work is to propose a series of courses of physics in medicine that would fulfill the requirements of any medical college.

Methods: The presented courses will be divided into three phases: premedical, pre-clinical, and clinical years for medical students. To do so, a critical analysis of the topics needed at the different phases and the possibilities of implementing this syllabus and constraints that may face the process is conducted.

Results: The different topics are shown and means of implementing them as a single subject or in conjunction with other subjects is clarified

Conclusion: Once properly tailored, physics can provide a strong tool in medical education.

1. INTRODUCTION

Physics has vast applications on biological sciences in both, microscopical level (where physics helps describe properties of the cells and their interaction with the environment) and the larger macroscopic level (where it explains the physical concepts such as heat and work, for instance, associated with the functions or organs and systems in the human body) examples include respiration, vision and audition phenomena. Physics has also revolutionized medical practice since the birth of medicine thousands of years ago. It provided us with a better understanding of our health problems through many diagnostic and treatment tools, such as ultrasonic blood flow measurements, X-rays, nuclear medicine, magnetic resonance imaging (MRI), radiotherapy and minimal access surgery (Tsekhmister, 2024; Melzer et al., 2012). Several medical schools do not fully implement physics as a main subject in their curriculum. Physics is a powerful subject that can be applied in many academic studies, particularly medicine. Unfortunately, in most medical schools, physics is only taught as a freshman year subject, and many medical students feel obliged to take it without knowing its real relevance to their future career. This is basically due to the lack of an appropriate course design, references and the poor commissioning of physics in the medical field. The aim of this work is to propose a series of courses of physics, especially tailored for medical colleges, that would replace the traditional approach for physics to fulfill the requirements of any medical colleges.

2. MATERIALS AND METHODS

In a previous paper (Omer et al., 2006) we discussed the important role of medical and biophysics for both, conventional education i.e. for medical physicists and medical and paramedical students and professionals. An extended physics syllabus that would fulfill the requirements of any medical school for the different years in medical schools is now presented. The proposed courses will be divided into three phases: premedical, pre-clinical and clinical years for medical students. A critical analysis of the topics needed at the different phases and the possibilities of implementing this syllabus and constraints that may face the process is conducted.

2.1 Premedical years:

These include the first one or two years at the school of medicine in some universities. In some countries like Canada and USA, the system is different. Medical students obtain a bachelor's degree in one of the natural or biological sciences field, then proceed to enroll in a medical school or college that offers a 3-4 years postgraduate: Doctor of Medicine (M.D. or M.D.C.M.) degree.

2.2 Preclinical years

Preclinical years refer to the first one or two years in medical education. Basic subject like physiology, biochemistry, anatomy and pathology are delivered in the pre-clinical years. Little clinical knowledge is obtained in this duration. Some of the main drawbacks faced are the lack of interest and poor retention of knowledge reported by students as they proceed to the clinical years (Custer, 2010; Alam, 2011). This is clearly reflected in some students in the pre-clinical years who perceive basic biomedical sciences as being irrelevant to clinical applications and study-to-pass the exams without appreciating the information given to them. The main cause for insufficient focus on basic sciences is quite evident in clinical rotations, where trainers lack sufficient knowledge on basic sciences and thus approach the training in a manner that belittles the relevance of basic science knowledge. Another element that reduces the interest of students in premedical years is the fact that science-centric questions were eliminated from medical board exams as USMLE Step 1 (Brass, 2000). The solution to this lies in educating the medical faculty in clinical years on the importance of integrating the basic sciences with clinical sciences as described in the basic plus clinical' medical model by Flexner (Flexner, 2002). A study by Aborajooh et al showed that the subject which is remembered most of the basic sciences was physiology. Physiology is the study of how biological systems act at the molecular, cellular and organ system level (Aborajooh et al., 2020; Gupta et al., 2014).

2.3 Clinical years:

Unlike preclinical years where learning occurs in lecture halls or laboratories; where learn hands-on in the laboratory settings as in anatomy, pathology and histology, clinical education is focused on rotations where students are exposed to real patients under the supervision of a tutor or sometimes specialists. Clinical faculty are very knowledgeable in clinical concepts but may not be very familiar with the scientific foundations of medicine. Hence, their approach to medical practice does not adequately reflect the value of science in decision making (Brass, 2000). Little is

DOI: https://doi.org/10.70274/medbiohealth.2024.1.1.18.
ISSN 3007-6374

explained about how the sound travels through lungs in both the normal and disease states (Goldszmidt et al., 2012) or how the thin layer of tears help cool down the eyes. Bone fixing depends on many physical parameters which need to be taught in clinical years. Even in the fields of radiation medicine such as nuclear medicine, diagnostic radiology or radiotherapy; the medical curriculum scans these topics with only sufficient information to pass the clinical exams. Very little physics is retained afterwards because it is not part of practice of life 'Praxis des Lebens' (Custer, 2010).

3. RESULTS

After thorough investigation of the topics the following syllabus is suggested. The topics which are taught in many universities are in line with our proposed syllabus.

3.1 Premedical Physics

The purpose of premedical physics is to build academic knowledge in several fields of physics. The proposed syllabus is written on the base of 2 hours theory and 2 hours laboratory work per week/ 30 weeks per academic year. Physics at this level will be taught with the objective of enriching the concepts that will be of use to the medical sciences. Different applications will be introduced to motivate the students in the study of physics. The syllabus focuses on improving the analytical skills, for example relate directly and indirectly proportional variables and interpreting graphs while making sure that students are not burdened with the rigors of mathematics and pure physics. At this level, basic subjects need to be introduced, equipped with laboratory facilities and simple simulations.

Units and measurements: this one-hour section will explain the different units used and conversion between them. It will explain unit prefixes such as kilo, mega, etc. It will also elaborate simple measurements such as length, area volume and the different units associated with them such as square, square root, cube as well as some trigonometric functions such as sin, cosine. Simple calculations using direct and indirect proportional will be introduced to the students.

Drawing and interpreting graphs: this one-hour section will explain the two axes for drawing a graph; how to draw a graph and what information can be obtained from that graph. It will be followed by a small assignment to make sure that all students have understood what is needed. Graphical representations, together with diagrams and sketching are very important tools that can be used to explain to patients and co-patients, especially those who cannot read properly some important aspects such as infants' weight and breast feeding.

Mechanics:

Mechanics is the science of motion. It basically consists of three branches: *kinematics*, which involves description of motion without explaining the causes for the motions, *dynamics* which relies on the causes of motion such as forces and energy; and *statics* or equilibrium. The topics will include the following:

Kinematics: (vector and scalar quantities, distance and displacement, speed and velocity, acceleration, graphical representation of motion and motion diagrams)

Dynamics: (force, energy, work and power)

Statics (torque, equilibrium centre of gravity and stability) and elasticity.

Thermodynamics:

Thermodynamics is the branch of physics that studies energy and transformation between a system and its surrounding at a macroscopic level.

The topics of thermodynamics include: temperature and heat, thermal expansion, unusual expansion of water and marine life, the thermometer and temperature scales, the absolute zero, thermal properties of matter, heat transfer, laws of thermodynamics.

Waves

When the word "waves" is mentioned, we immediately think of wind waves; waves in oceans and seas, waves made by football fans as well as light and sound. Waves will be divided into two sections. The first one (Waves 1), introduces waves and the different phenomena and focuses on mechanical waves. The second section (Waves 2), will focus on electromagnetic waves. The topics suggested include:

Waves 1: Oscillation and vibrations waves, the wave equation, electromagnetic Vs mechanical waves, Mechanical waves section includes: transverse and longitudinal waves, travelling and

DOI: https://doi.org/10.70274/medbiohealth.2024.1.1.18.
ISSN 3007-6374

standing waves. *Sound waves*: speed, frequency and, energy, intensity, power and loudness, intensity level in dB, resonance, modes of vibration in half-open pipes, acoustic impedance, doppler effect, and ultrasound.
Waves 2: the electromagnetic spectrum, light and optics: modelling of light, reflection and refraction, lenses, LASER: lasing action, fundamentals and classifications. Other waves are also introduced including, microwaves, infrared, ultraviolet radiation.

Fluid mechanics:
This section explains deformation and motion of fluids: liquids and gases, when subjected to shear forces or as the result of pressure. It also explains the behavior of fluids while crossing barriers or areas of different dimensions example cross-sectional areas or heights. The suggested topics include: the three phases of matter, fluids: gases and liquids, ideal gas law, Boyle's law, osmosis, diffusion mechanism of breathing, surface tension, liquids, hydrostatics: density, volume, pressure; hydro-dynamics: non-viscous flow: continuity and Bernoulli's equations, viscous flow: Poiseuille's law and viscosity, laminar and turbulent flow.
Electricity:
Electricity studies the motion of charged particles within a conductor or resistor. The suggested topics include: nature of charges, simple circuits and Ohm's law, electric force, field, electric potential, potential energy, potential difference, capacitors.

Radiation:
Radiation is the emission or transmission of energy in the form of electromagnetic waves which are associated with oscillations in electric and magnetic fields with specific frequency and wave length such that the product of them, which is the velocity of the wave has a constant value: $c=2.9979\times10^{8}$ m/s. Radiation can be ionizing or nonionizing. The topics suggested for radiation include:
Nonionizing radiation: The structure of atomic nucleus, energy levels and excitation of atoms, the electromagnetic spectrum, cosmic nonionizing radiation, interaction of nonionizing radiation with matter, man-made radiation.
Ionizing radiation: natural and artificial radiation, atoms, ions, isotopes, isobars. X-rays and Gamma rays, scatter, penetration power, stable and unstable nuclei, forces within the nucleus, nuclear decay, the half-lives in decay, activity, dose and measurements.

Computation in medicine:
Computation in medicine applies mathematical concepts to produce algorithms that are applicable in medical imaging and analysis (Adeshina et al., 2017). Topics suggested include: artificial intelligence, Monte Carlo based calculations, phantoms, simulation, and treatment planning.

Integration with other basic sciences
Integration with other topics is not an easy task at this level because the subjects are delivered by experts in one of the basic sciences only, for example physics, and little do they know about the other subjects. The most appropriate way is to have a committee from the three basic science disciplines who would re-arrange the syllabus such that similar topics are taught at the same time. For instance: energy and metabolism, waves and the senses etc. can be taught simultaneously so that the information given in physics and chemistry could be linked with the biology of the human body without repetition. Humans have five vital organs: the brain, heart, kidneys, liver and lungs. The human body has other systems where physics integrated with physiology can explain their functions and what can go wrong.

3.2 Preclinical physics and physiology or biochemistry

The integumentary system or skin
This is the largest organ in the human body that surrounds and protects the internal body from cosmic rays, bacteria and pathogens. It also plays a major role in thermal regulation of the body temperature and waste elimination through perspiration.

The digestive system
Consists of a series of connected organs. These organs function together to allow the body to break down and absorb food, and remove waste.
Thermal Physics topics explain the functions of these two systems.
The suggested topics include: metabolism: food and exercise, thermal regulation, hypo-and-

DOI: https://doi.org/10.70274/medbiohealth.2024.1.1.18.
ISSN 3007-6374

hyperthermia, warm-blooded and cold-blooded animals, hibernation and estivation.

The Musculo-skeletal system

This consists of the skeletal system (of 206 bones) that provides protection of some organs as well as support and thus posture of the body, and the connective muscular system (that consists of about 650 muscles connected by tendons, ligaments and cartilage). It helps in: movement, blood flow and other bodily functions.

The physics topics that can explain the function of the musculoskeletal system is called **Biomechanics**. Topics included in the suggested course are:

Forces on joints and bones, the composition of bones and joints that allow them to withstand such forces), viscoelastic properties of muscles and tendons, posture and gait analysis, diseases affecting our locomotor-system, a brief introduction to nerve conduction and muscle contractions. Car crashes and effects on the neck (whip-lash).

The circulatory system (a)

Blood motion, which carries nutrients, oxygen, carbon dioxide, and hormones, around the body is done in the circulatory system. It consists of the heart, arteries, veins and capillaries.

The respiratory system (b)

This system allows gas exchange in the body, where oxygen is taken in during inhaling and carbon dioxide is expelled out during exhaling. It consists mainly of the nose or mouth, the trachea, the diaphragm and the lungs.

The urinary system (c)

When certain foods are broken down, a toxic product known as urea is formed, which is in turn extracted by the urinary system. The urinary system includes the kidneys, the ureters, the bladder, the sphincter muscles and the urethra.

The three mentioned systems (a, b and c) utilize fluid motion**.** *Biofluids* can demonstrate the functions of these systems. The suggested topics include:

Mechanism of breathing, surface tension and surfactant, asthma and flu and effects on breathing the circulatory system, heart valves and blood flow, blood flow from peripheral vessels arteriosclerosis, turbulence and blood pressure measurement, the urinary tract, osmosis and hyper-filtration.

The nervous system

The nervous system functions as a result of signals transported from the body via the nerves to the brain. These signals control both voluntary action and involuntary actions. The nervous system consists of a central nervous system, (which includes the brain and spinal cord), and the peripheral nervous system (which consists of nerves that connect every other part of the body to the central nervous system). The physics topics related to the nervous system include:

Electricity: Sodium-Potassium channels, action potential, the neuron, and nervous system, pain and muscle simulation, cardiac muscle cells, ECG, EMG, EEG, and ECT.

Waves: anatomy and physiology of the ear, phonation and audition, sound in medicine: stethoscope, lung and heart murmurs, sphygmomanometer, flu and vocal cord problems, problems of hearing, rapture of the ear drum

Waves 2: Anatomy and physiology of the eye, day-time and night-time vision, color-blindness, night-blindness, optical instruments: lenses and corrections of vision defects, magnifying lens, microscope, ophthalmoscope, intra-ocular pressure: tonometry and glaucoma. Vision correction: using lenses.

Physics can be used in diagnosis and therapy of these and other systems as is explained in the next section.

Following are some medical specializations that are taught to students in clinical years' theory and rotations. The related physics topics that will be useful to students are presented with each specialization.

3.3 Physics and clinical rotations

Orthopedics:

Biomechanics and Biomaterials: Biocompatibility and biomaterials, prosthesis and orthosis

Ear nose and throat (ENT), gynecology and surgery:

Waves 1: hearing defects, cochlear implantations, medical applications of ultrasound: fetus heart and deformities, Doppler ultrasound, kidney stones and lithotripsy, ultrasound guided

DOI: https://doi.org/10.70274/medbiohealth.2024.1.1.18.
ISSN 3007-6374

therapy, other applications of ultrasound in medicine.

Ophthalmology, dermatology and cosmetics:
Waves 2: LASER therapy of the eye, skin, LASER cosmetics

Urology, cardiology, medicine and surgery (any specialization dealing with fluids flow:
Biofluids: Heart valves, hemodialysis, bypass operations

Neurology:
Electricity: Nerve conduction, multiple sclerosis, diabetic neuropathy, electric shocks and home safety

General medicine, cosmetics, surgery, etc.
Non-ionizing radiation: nature, hazards, and protection from and medical applications of: ultraviolet radiation, visible light, LASER surgery infrared radiation and microwaves,

Radiology, nuclear medicine, radiotherapy and oncology: The clinical practice of radiology rests on a physics foundation. Medical Physics facilitates clinical interpretation and decision making (Samei & Grist, 2018; Jordan et al., 2019). This is of importance in radiation oncology, where dose calculations based on physics allows to efficiently utilize radiation while minimizing harmful effects on both medical personnel and patients. Doctors may make wrong decisions; for example, decide termination of pregnancy for a woman who underwent diagnostic or nuclear imaging. A fetus would be saved if the doctor knew how to evaluate the hazards to the fetus associated with the specific test, or who to refer to for advice. The suggested topics in Ionizing Radiation include:
Radiobiology, medical imaging: nuclear medicine and x-rays, radiotherapy, radiation protections legislations and protocols. Gaining access to medical physics departments in the hospital to learn dose calculations, risk assessment, treatment planning, etc. would provide medical students with adequate and useful knowledge.

4. DISCUSSION

Recently, medical education has been broken up into segregated sciences: basic and clinical sciences (Bandiera et al., 2013). This has led to a considerable disconnect between the sciences which promoted students to perceive basic sciences as a burden against reaching clinical training (Teshome. Et al., 2021; (Shah et al., 2015). The medical model that combines these sciences was initially described in the report by Flexner (Flexner, 2002). It stems from a strong belief that understanding basic sciences facilitates understanding clinical medicine. It aids in fact recall, contributes to better diagnostic formulations, and assists in solving complex and atypical clinical scenarios. The main constraints against designing and implementing such extended series of courses can be summarized as follows:

4.1 *Interested and knowledgeable faculty members:*

Physics is not fully utilized in medical education because it is not tailored to cover the topics needed in the appropriate times or phases of medical studies. It can play a major role at the schools of medicine at pre-medical, pre-clinical, and clinical levels if proper courses are designed and advertised. Unfortunately, many of those working in medical schools are either medical doctors who cannot visualize physics as a necessary tool or pure physicist who stick to the old fashioned mathematically oriented physics with little implementation in the human body or medical physicists who design courses on radiology and MRI, etc. for students who do not know the basics.

4.2 *Facilities:*

Laboratories, whether physical or virtual, are designed to educate students with specific subject-oriented experiments: biology, physics, biochemistry, etc. Integrated laboratories are needed to implement such extended series of courses.

4.3 *Books:*

There are many books that cover physics for medicine. Most of them use more specialized physics terminology and complicated mathematical equations that are too difficult for medical students and would minimize their interest in the books. Dedicated books that address medical students are needed. These books need a team of authors specialized in the different subjects as well as medical education to

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ISSN 3007-6374

discuss each chapter and find ways to integrate or even dissolve/fuse the subjects into a single topic that is easy to comprehend and retain.

4.4 ***Administration or Scientific council approval:*** The process of approving a university curriculum and even ranking a university is a long and intensive one. A question arises; will those universities accept to make a change in the whole system and a shift towards a multidisciplinary or integrated course and undertake the challenge for another time? Moreover, students and faculty at the medical schools are already burdened with extensive applied and clinical sciences. Proposing to add other courses that demands more efforts for design, establishment and integrating with the already time-and-energy consuming curriculum is a challenge. Courses that make use of simulations such as physics applets: Physlets (Christian & Belloni, 2015) and Physics Education Technology: PhETs (Perkins et al., 2006) or games (Kortemeyer, 2019) can provide solutions by linking physics to medicine in a smooth way. Richardson and Amini used a scientific notebook software known as Project Jupyter, which enabled them to blend together a mixture of explicatory text, images, computations, plots, interactive widgets, and audio files. This provided a rich educational environment which allowed students to change the image parameters and notice the influence in real time (Richardson & Amini, 2018).

5. CONCLUSION

Physics is a powerful tool in medicine. A six-year course can be designed for the three phases with combined efforts from professionals who wish to join efforts to maximize the benefits of this subject.

Medical schools wishing to test the feasibility of changing a syllabus that has been reviewed by international academic panels need to be found and contacted. Reputable biomedical/biophysics departments need to be contacted and requested to share their experience. Training of staff willing to tailor physics to match the needs of the different phases is an important element in this process and is thus a vital part of the proposed course. Thorough analysis of the potentials of designing and implementing this course needs to be discussed. Educational strategies based on gamification to simplify physics concepts in relation to health and disease should be adopted to engage students. Changing the long-believed physics based on classical mathematical concepts to a subject that can be tailored to suit the needs of the demanding and quickly developing medical world is a target. It needs hard work to design a six-year syllabus. But most important, it needs dedicated professionals: who believe in the power of physics in medicine and integration with biology, physiology and other relevant health subjects.

ACKNOWLEDGEMENT:

The authors would like to express their gratitude to Professor Caruana (Malta) and Professor Suleiman (KSA) and Dr. Mona Alshaikh (KSA) for their fruitful discussions and brain storming efforts.

FUNDING:

This research received no external funding

AUTHOR CONTRIBUTIONS:

H.O. designed and performed the experiments, Conceptualization, H.O., H.T. and E.A.; methodology, H.O.; validation, H.T. and E.A investigation, H.O..; data presentation, H.O.; scientific writing and manuscript preparation, H.T. and E.A.; manuscript revision and editing, H.T. and E.A.; proof reading, H.O.; supervision, project administration. All authors reviewed and approved the manuscript.

CONFLICTS OF INTEREST:

The authors declare no conflicts of interest.

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DOI: https://doi.org/10.70274/medbiohealth.2024.1.1.18.
ISSN 3007-6374