Optimization of Undergraduate BME Curricula for Students Seeking Careers in Clinical Medicine

Richard J. Jendrucko, Jack F. Wasserman
University of Tennessee, Knoxville

Biomedical engineering (BME) academic programs are generally designed to meet the needs of employers including biomedical industries, government agencies and clinical service entities (e.g. hospitals). Additionally, undergraduate BME programs are structured to meet all ABET accreditation requirements which include a plan for continuous program improvement. Based on an overall philosophy of integrating the life sciences with engineering topical material, undergraduate BME programs include courses in mathematics, the physical and life sciences, engineering sciences (e.g. electric circuits, heat transfer) and a group of specialty BME courses. The latter may include biomechanics, biomaterials, bioinstrumentation, biotransport processes, BME laboratory and a senior design experience among other areas.

Not surprisingly, as students at major universities become knowledgeable of the existence of an undergraduate BME program (e.g. via catalog or web site review), they consider the utility of an interdisciplinary degree in BME for the pursuit of careers other than the traditional set listed above. In particular, it has been common for students pursuing careers in the health sciences (including medicine, dentistry, pharmacology and other disciplines) to select BME for a preparatory undergraduate major. This choice appears advantageous in view of the substantial life and physical sciences content of most BME curricula that allow the satisfaction of common health sciences program entrance requirements. Additionally, some students feel that the pursuit of an engineering degree allows for a back-up professional career if their intentions change or if they are not successful in gaining acceptance to an advanced health-sciences program. For these reasons, undergraduate BME programs have reported fractions as high as 25% or more of their students intending medical school or another health sciences program.

The fact that sizable fractions of undergraduate BME students plan for health sciences careers may be viewed in several positive aspects. Firstly, it would appear desirable to graduate physicians and other health professionals who have the strongest possible background acquired during their undergraduate studies. Biomedical engineering curricula include blocks of physical, life and engineering sciences and train students in effective problem solving techniques and effective communication. In addition, with the goal of maintaining a high level of BME program quality, it is attractive to have enrolled many health profession-bound students who generally have superior academic credentials. These students enhance the classroom experiences of both their fellow students and the teaching faculty. Clearly, the enrollment of pre-health science students can substantially enhance the overall quality of any undergraduate BME program.

It is of interest of consider the desirability of BME as a pre-health science program from the standpoint of the students applying for admission to medical and other health sciences schools. As an example, typical minimum pre-entry requirements for medical school include:

- English composition (1 year)
- General chemistry (1 year)
- General biology (1 year)
- Organic chemistry (1 year)

Particular schools may require additional specific courses to have been completed. In addition, admission to health sciences professional programs may be enhanced by completion of other medical science-related courses such as human physiology and anatomy. Most currently available undergraduate BME curricula include English, general chemistry and biology requirements. Many programs (including the University of Tennessee program) incorporate elective hours sufficient to accommodate the organic chemistry requirement.

Since it is clear that significant numbers of undergraduate (and some graduate) BME students intend the pursuit of a medical or other health science degree, it is appropriate to consider how well BME programs prepare them for their intended careers. In the discussion that follows, consideration will be limited to medical school and the practice of medicine. Similar arguments can be made for other health science professions.

The nature of the practice of medicine depends on the specific medical specialty and the conditions of practice (e.g. private office, hospital, medical research institution). However, as a generalization is can be stated that the talents needed include:

- A thorough knowledge of normal human body structure and function, pathologies and treatments available (related to specialization, if any)
- Proficiency in observation and "hands-on" diagnostic assessment
- Manual dexterity required for surgery and precision-based procedures
- The ability to rapidly make effective assessment and treatment decisions

It is clear that undergraduate BME education can contribute meaningfully to gaining proficiency in one or more of these areas. Most BME curricula include some coursework that includes treatment of normal human body anatomy and physiology. In some cases this coverage is integrated with engineering material (e.g. The University of Tennessee's course BME 310: Engineering Physiology which presents physiological principles with selected example BME applications). The coverage of pathologies is typically more limited and is often included in case studies discussed in class. Coverage of treatments is normally presented in terms of the design of medical devices or systems used in patient treatment.

Most BME curricula are limited in experience gained in patient observation and diagnosis. However, to meet ABET accreditation requirements all programs must include a "hands-on" laboratory experience with living system elements. A medically relevant experiment set might require the measurement and analysis of bio-electric signals or the use of a signal simulator (e.g. the University of Tennessee's course BME 430: BME Laboratory). The development of manual dexterity useful to the performance of specific medical procedures is typically not possible in the context of a typical undergraduate BME laboratory course. Finally, the extent to which a BME curriculum experience can foster a proficiency with rapid problem solving depends on the specific learning methods used in the BME and other courses. This subject is discussed further below.

In a further analysis it may appear that the utility of a BME education to a future medical practice depends in large measure on a practitioner's medical specialization. In a review of the US Bureau of Labor Statistics 1999 data for medical practitioners, the fraction of the total numbers of physicians practicing in various specialties in decreasing order is:

16.1% Internal medicine
10.7% Family medicine
7.5% Pediatrics
4.9% Obstetrics and gynecology
4.9% General surgery
4.9% Psychiatry
4.4% Anesthesiology
2.8% Emergency medicine
2.7% Orthopedic surgery
2.6% Diagnostic radiology
2.5% Cardiovascular diseases
2.3% Pathology
2.2% Opthalmology
31.5% All other specializations (<2% in each remaining category)

A general observation for this listing is that no single specialty practice area dominates the distribution. The first six entries comprise only 49% of the total number of practicing physicians. Thus, it appears that BME curricula could not effectively target a small number of dominant specialties but instead the focus should be on specific BME topics relevant to most medical specialties. Undergraduate BME curricula commonly include courses or significant experiences in the following listed areas where the apparent relevance to clinical practice is identified.

- <u>Life sciences</u> (cellular and organ systems, anatomy, physiology)
  Clearly, this area is relevant to medical practice in all specialty areas to a significant extent. Coverage in a BME program will enhance the learning of these topics in medical school and would be expected to favorably impact patient care.

- <u>Mathematical analysis</u> (calculus, differential equations, statistics)
  In general, the level of mathematics included in BME curricula is significantly beyond the level useful for most practicing physicians. An exception is statistics, the knowledge of which is useful in interpreting clinical studies published in medical journals.

- Bioinstrumentation
  The performance of physical measurements, many with microprocessor-based electronic systems is common in medical practice. All practicing physicians would likely benefit from a basic understanding of measurement systems, signal processing and measurement accuracy and precision. This knowledge would be expected to be particularly useful to emergency care practitioners, anesthesiologists and internists.

- Biomechanics
  Knowledge of basic quantitative biomechanics would be expected to be of general use to physicians in most specialty areas perhaps excepting obstetrics and gynecology, psychiatry, anesthesiology, diagnostic radiology and pathology. Knowledge in this area is of particular relevance to the practice of orthopedic surgeons.

- Biomaterials
  A knowledge of biomaterials is of particular benefit to orthopedic and cardiovascular surgeons who routinely use various commercially-produced implants. The utility of biomaterials knowledge is limited for most other medical specialists.

- Bio-transport processes
  This subject is normally treated in BME programs as the quantitative analysis of basic physiological processes. In some respects, coverage is in essence, quantitative physiology. Relevance is limited with regard to routine patient care in most medical specialties.

- Engineering sciences (engineering materials, mechanics of materials, fluid mechanics, thermodynamics, heat transfer, electric and electronic circuits)
  The relevance of engineering sciences as they are traditionally taught has limited value for most practicing physicians. An exception is the category of electric and electronic circuits which is directly related to bioinstrumentation as discussed above.

- Information technologies (e.g. use of computers, Internet)
  Experience gained with modern information technologies, particularly the use of computer systems for patient medical records and billing, and for data searches on the Internet is of substantial interest to many, and especially more-recently-trained physicians.

- <u>Special topics</u>
  A variety of topics typically covered in a BME seminar course would be of benefit to all practicing physicians. Subjects such as the US health system, trends in patient care and FDA regulation of medical devices would be of obvious interest to many physicians.

The analysis summarized above suggests that overall, the technical content of a typical undergraduate BME program has on average, at least a moderate level of benefit to those students who go on to become practicing physicians. While the life sciences and information system content of a BME curriculum has wide applicability and utility, specialized BME topics such as biomaterials are of limited relevance and interest to physicians in many specializations. It seems apparent that if BME coursework is to maximally benefit future physicians, the focus should be on expanding the curriculum time devoted to life sciences and information technologies while presenting selected subjects (e.g. biomaterials) as electives. Of course, since the majority of students graduating from most undergraduate programs are not intending careers in medicine, in the balance, program design should favor more traditional careers.

Finally, if the overall operational aspects of BME instructional programs are considered, there are additional significant benefits to future practicing physicians beyond the raw content of curricular courses. In particular, BME curricula are built on a philosophy of students learning problem-solving methods. The extent to which BME curricula incorporate opportunities to develop general problem-solving skills (problem definition, development and evaluation of solution alternatives, select chosen alternative and construct system or device) future physicians will benefit from this training. As in some engineering practice environments, physicians are faced with having to make treatment decisions in a short time frame with often-limited information. Thus, the extent to which general engineering skills are acquired in a BME program should be maximized not only for the benefit of graduates practicing in traditional roles but also to benefit future physicians.

A final consideration is the extent to which physicians trained as BME's can benefit from curricula using structured learning methods. Such methods as process education wherein students are given a high level of responsibility for their own learning have been shown to facilitate the building of those personal operational skills that are needed by physicians in a clinical practice setting.

In summary, it has been shown that in most cases, a BME pre-medical training has significant benefits to graduates who go on to medical school and the practice of clinical medicine. This student group benefits particularly from life sciences and information technology content. The varying needs of medical specialists can be best met by including sufficient elective hours and available special BME courses to satisfy special knowledge needs. In this way, both BME students intending traditional careers and those planning a career in medicine can achieve a curriculum experience satisfying their particular needs.

RICHARD JENDRUCKO
Richard Jendrucko is currently Professor and Associate Department Head in the Department of Mechanical, Aerospace and Biomedical Engineering . He has been active in biomedical engineering for over twenty-five years. Professor Jendrucko has also served as ASEE Biomedical Engineering Division Chair.
Richard Jendrucko may be contacted at The University of Tennessee, College of Engineering, MABE Department, 301 Perkins Hall, Knoxville, TN 37996-2030; TEL (865) 974-7682, FAX (865) 974-5274; jendrucko@utk.edu.

JACK WASSERMAN
Jack Wasserman is a professor in the Department of Mechanical, Aerospace and Biomedical Engineering where he has taught in the biomedical engineering program for over twenty-five years. Professor Wasserman is the recipient of seven teaching awards and he holds the position of Fellow in the Center for Undergraduate Excellence and the Interactive Technology Center at the University of Tennessee, Knoxville. *Jack Wasserman can be contacted at The University of Tennessee, College of Engineering, MABE Department, 322 Perkins Hall, Knoxville, TN 37996-2030, TEL (865) 974-7678, FAX 974-5274; jack-wasserman@utk.edu.*