Bioengineering/biomedical engineering education

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Handbook of Research on Biomedical Engineering Education and Advanced Bioengineering Learning:

Interdisciplinary Concepts

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Chapter 1
Bioengineering/Biomedical Engineering Education

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ABSTRACT

Bioengineering/biomedical engineering education is a social process integrating accrued knowledge, expertise, and values pertaining to a fusion of engineering sciences and biomedical sciences that have been disseminated across generations. It has evolved since 1959, and is currently undergoing a healthy global growth. This chapter provides a methodical and comprehensive study on bioengineering/biomedical engineering education. It is addressed to the international bioengineering/biomedical engineering researchers, faculty, and university/college students, as well as, practitioners in bioengineering/biomedical engineering, along with other closely-related governmental, non-governmental, and industrial entities.

1.1. CHAPTER OBJECTIVES

- To provide a formal definition of bioengineering/biomedical engineering and elucidate the role of higher education in this field.
- To provide an in-depth overview on the evolution of bioengineering/biomedical engineering education supported by a thorough literature review.
- To provide a detailed presentation of state-of-the-art curriculum philosophies in bioengineering/biomedical engineering.
- To provide an insight into existing academic curricula in bioengineering/biomedical engineering, supported by a prototype of a modern well-developed undergraduate curriculum in the field.
- To provide educated recommendations about career development in bioengineering/biomedical engineering.

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- To provide an analytical comprehensive study on the world promulgation of bioengineering/biomedical engineering education.
- To provide a forecast of the future of bioengineering/biomedical engineering education.
- To provide a listing of the professional societies and organizations in bioengineering/biomedical engineering.

1.2. INTRODUCTION

Bioengineering/Biomedical Engineering is acclaimed as one of the most advanced fields in science and technology worldwide, and has spurred the advancements in medicine and biology. Recently, healthcare practices have been steered towards new emerging frontiers, including, among others, functional medical imaging, regenerative medicine, nanobiomedicine, enzyme engineering, and artificial sensory substitution. Concurrently, bioengineering/biomedical engineering education has been evolving and proliferating since the late 1950s (Harris *et al.*, 2002; Harris, 2003; Linsenmeier *et al.*, 2002). Today, bioengineering/biomedical engineering education is globally undergoing a healthy growth with 704 programs offered in 6.73% of the world universities (Abu-Faraj, 2010). The first program to be officially launched in biomedical engineering was at Drexel University, Philadelphia, PA, USA, in 1959 at the master's level. This program was soon followed by Ph.D. programs at Johns Hopkins University, Baltimore, MD, USA, and the University of Pennsylvania, Philadelphia, PA, USA (Pilkington *et al.*, 1989). At present, a surge in the development of new curricula in bioengineering/biomedical engineering around the world is witnessed, especially in developing and transitional countries. These programs are to some extent diverse and vary in their academic content, as well as within the different tracks constituting the various areas of bioengineering/biomedical engineering, which are highlighted in Section 1.3 - Comprehensive Definition of Bioengineering/Biomedical Engineering Education.

Prior to expounding, a word of caution is in order about the use of bioengineering and biomedical engineering terminology within a professional context as there exist some inconsistencies regarding the utilizations of these two terms. To some authorities the term bioengineering is considered as a '*broad umbrella*' that covers biological engineering, biomedical engineering, medical engineering (also known as clinical engineering), as well as biochemical engineering (Pacela, 1990; Domach, 2004). To others bioengineering is regarded as "*a basic-research-oriented activity closely related to biotechnology and genetic engineering*"; whereas, to these authorities, biomedical engineering is the '*broad umbrella*' that encompasses the above areas among others (Bronzino, 2005). Despite these discrepancies introduced by common practice, it should be noted that a great degree of overlap between these two fields exists. In this regard, such ambiguity could be resolved by looking at it from morphological and occupational perspectives. From a morphological approach, the terms bioengineering and biomedical engineering can be differentiated by the absence of the word '*medical*', which is defined in the dictionary as 'the practice of medicine' and that in turn is implemented in both bioengineering and biomedical engineering. Thus, there exists no dichotomy between these two terms, but as a matter of fact they are complementary to one another. From an occupational angle, Harmon stated in 1975 that "Bioengineering is usually viewed broadly as a basic-understanding field which uses the tools and concepts of the physical sciences to analyze biological systems; thus it is largely research oriented and not necessarily related to medical problems" (Harmon, 1975). He added that "While the prime focus of biomedical engineering is on utility, it combines clinical emphasis with strong commitment to basic research". Another expert opinion on this subject matter was voiced by Katona when he asserted that "there is no consistent distinction between academic departments bearing one or the other designation and the two terms are often used interchangeably" (Katona, 2002). Undoubtedly, the 21st century mirrors an epoch of medical renaissance that encompasses and fosters both fields. Accordingly, this text refers to bioengineering and biomedical engineering interchangeably and in depth.

This chapter provides a formal definition of bioengineering/biomedical engineering education and an in-depth overview of its evolution; in addition to a detailed description of state-of-the-art curriculum philosophies, and an insight into existing academic curricula, to end with recommendations about career development and an analytical analysis of the world of bioengineering/biomedical engineering education. The chapter does not only address the international bioengineering/biomedical engineering researchers, faculty, and university/college students, but it is also intended to provide a set of strategies and recommendations to be pursued by individuals and/or entities seeking to plan and design careers and/or curricula in this field, as well as in research and development (R&D) for research scientists and practitioners in bioengineering/biomedical engineering, and other closely-related vocational professions.

1.3. A COMPREHENSIVE DEFINITION OF BIOENGINEERING/BIOMEDICAL ENGINEERING EDUCATION

Before expounding, it is essential to provide a set of comprehensive definitions around bioengineering and biomedical engineering, and to highlight the key divisions within this field.

Bioengineering/Biomedical Engineering Education could be defined as a social process whereby accrued knowledge, expertise, and values pertaining to an amalgam of engineering sciences and biomedical sciences are disseminated throughout generations.

The working definition of Bioengineering according to the National Institutes of Health, Bethesda, MD, USA, is (Anonymous, 1997): "Bioengineering integrates physical, chemical, or mathematical sciences and engineering principles for the study of biology, medicine, behavior, or health. It advances fundamental concepts, creates knowledge for the molecular to the organ systems levels, and develops innovative biologics, materials, processes, implants, devices, and informatics approaches for the prevention, diagnosis, and treatment of disease, for patient rehabilitation, and for improving health."

The Whitaker Foundation defined Biomedical Engineering as (Anonymous, 2006a): "A discipline that advances knowledge in engineering, biology and medicine, and improves human health through cross-disciplinary activities that integrate the engineering sciences with the biomedical sciences and clinical practice. It includes:

1. The acquisition of new knowledge and understanding of living systems through the innovative and substantive application of experimental and analytical techniques based on the engineering sciences.
2. The development of new devices, algorithms, processes and systems that advance biology and medicine and improve medical practice and health care delivery."

As for the Biomedical Engineer, the Biomedical Engineering Society, Landover, MD, USA, provided the following definition (Anonymous, 1996): "A biomedical engineer uses traditional engineering expertise to analyze and solve problems in biology and medicine, providing an overall enhancement of health care. Students choose the biomedical engineering field to be of service to people, to partake of the excitement of working with living systems, and to apply advanced technology to the complex problems of medical care.

The biomedical engineer works with other health care professionals including physicians, nurses, therapists and technicians. Biomedical engineers may be called upon in a wide range of capacities: to design instruments, devices, and software, to bring together knowledge from many technical sources to develop new procedures, or to conduct research needed to solve clinical problems."

Biomedical Engineering has been classified into 15 key divisions (Bronzino, 2005; Bronzino 2006). Today, together with education, which is described in this chapter, Bioengineering/Biomedical Engineering encompasses 20 key divisions in the following areas: artificial organs; assistive technology and rehabilitation engineering; bioelectromagnetism; bioethics; biomaterials; biomechanics; biomedical instrumentation; biomedical sensors; bionanotechnology; biorobotics and biomechatronics; biotechnology; clinical engineering; medical and bioinformatics; medical and biological analysis; medical imaging; neural engineering; physiological systems modeling, simulation, and control; prosthetic and orthotic devices; and tissue engineering and regenerative medicine. This list of interconnected and at times overlapping constituents contains modifications from that reported by Bronzino (Abu-Faraj, 2008), in addition to new emerging areas in the field such as Biorobotics (Webb and Consi, 2001) and Biomechatronics (Pons, 2008). Each of the 20 key divisions of Bioengineering/Biomedical Engineering could be considered as a field of study or research in its own right.

1.4. HISTORICAL BACKGROUND AND LITERATURE OVERVIEW

In March 1975, the *IEEE Transactions on Biomedical Engineering* published what could be considered as one of the earliest comprehensive literature debates around Biomedical Engineering Education and Employment (Harmon, 1975). This special issue was comprised of 13 papers that, according to Harmon, discussed many of the challenges pertaining to biomedical engineering as "a relatively new interdisciplinary profession striving for identity, quality control, and acceptance" (Harmon, 1975). Ten of these papers were found relevant to the subject matter of this chapter and, thereby, are presented herein.

Subsequent to his statement that after a decade, "The first period of diverse exploratory growth of biomedical engineering is now over and assessable", Harmon, in his article, raised a set of meta-questions pertaining to biomedical engineering education, specifically "*how to do what, with which, and to whom*" (Harmon, 1975). He stated that biomedical engineering is a combination of several disciplines; a fact that makes the range of problems which the biomedical engineer has to tackle impressively large. He further declared that "It is obvious that no single educational plan or establishment can readily encompass the great diversity of requirements in biomedical engineering training. We need specialists, generalists, multi-discipline hybrids, teams, researchers, practitioners, support technicians, teachers, and administrators - all in considerable sub-species variety." Harmon concluded his article by recommending that since the ultimate role of the biomedical engineer is to serve society, emphasis in biomedical engineering education should be centered on application rather than on research. Subsequently, flexible modular provisions within the multi-tracked biomedical engineering programs are needed so as to dispense equally heterogeneous biomedical engineering practitioners. In a paper entitled "*A Collaborative Approach to Bioengineering Education*", Moritz and Huntsman added emphases to Harmon's points of view, when stating that the "accommodation of the varied educational and research aspects of bioengineering has been a challenge to the imagination and flexibility of the traditional university departmental structure" and that "bioengineering by its very nature is interdisciplinary and must, by definition, cross departmental and even college or school boundaries" (Moritz and Huntsman, 1975). The authors then proclaimed that a basic philosophy pertaining to bioengineers and their training has to be established first so as to provide a foundation upon which the bioengineering program will be built. In this context, they compared and contrasted two distinct, yet competitive, philosophical approaches that have been employed in the preparation of individuals to work in this interdisciplinary field, namely: i) the "*hybrid approach*" and the "*collaborative approach*". Taking the University of Washington, Seattle, WA, USA, as a reference that had successfully adopted the latter approach, and in which the Center for Bioengineering had been deliberately chosen as "an organizational unit which has neither all the rights nor privileges of a department but has status in both the College of Engineering and the School of Medicine", the authors aimed to demonstrate that the "*collaborative approach*", which is characterized by a team approach of physicians and engineers to life sciences problems, was superior to the "*hybrid approach*". The authors further clarified that in the "*hybrid approach*" the student is solely intended to "be trained so as to be capable of independent decisions regarding interdisciplinary research directions" and that "often the training given in such a program is equally split between engineering and the life sciences". They added that the advantage of this approach lies in the fact that "the '*hybrid*' should be able to formulate, in engineering terms, the significant medical or life science problems that are amenable to engineering solutions… Such an individual may have insights into the medical aspects of a particular problem that would be difficult for an engineer to identify or appreciate". Notwithstanding this significant advantage, the authors found it lacking in many aspects when compared to the "*collaborative approach*" which mandates the following conditions to be present between physicians and engineers for its success: i) the ability of collaborators to communicate effectively with each other; ii) professional respect among team members; iii) possession of compatible personalities; and iv) significant commitments in terms of time and energy. The authors concluded their paper by stating that, based on their experience with the "*collaborative approach*", the *engineer* has brought to the team an analytical approach and techniques not attained by medical collaborators, and that the *life scientist* has been able to learn a great deal about physical sciences in a short period of time. In another paper, Jacobs discussed the sociological and technological factors that were critical in the genesis of the science of biomedical engineering (Jacobs, 1975). He debated about the fact that biomedical engineering has become a recognized health-related profession due to its marked difference from that of the traditional engineering disciplines. He further commented that since the biomedical engineer is expected to deal effectively with individuals of diverse skills and interests, he/she is to undergo "specialized formal training at the undergraduate level" so as to become apt at managing and planning intricate and vital mundane operations within the field. Jacobs concluded that such a demand for well-trained individuals in biomedical engineering sciences was perceived to be '*insatiable*', at that time. Johns' view in his paper, '*Current Issues in Biomedical Engineering Education*', revolved around the fact that biomedical engineering is "broad both in its biomedical and in its engineering components". He recommended that in order to "survive, much less prosper" in the field of biomedical engineering, it is imperative to recognize, forecast, and respond in a timely manner to the rapid political, social, and economical environmental changes so as to define and set the aspired goals and objectives of educational programs in this field (Johns, 1975). In his paper, Weed debated whether biomedical engineering should be '*practice or research?*' or '*practice and research?*' (Weed, 1975). He stated that, at the time, biomedical engineering was recognized, in universities and medical research hospitals, as a field that tended to produce a biophysics-physiology research-oriented biomedical engineer; thus, causing a major deficit in the employment of this biomedical engineer in the biomedical industry that preferred the classical electrical, mechanical, or computer engineer. However, he believed that "When industry can determine that the educational program has produced a competent electrical, mechanical or other engineer with added knowledge and capability in life science, there is no employment problem." Weed supported this statement with numerical facts when he stated that "Today, nearly 200 universities have an identifiable program in biomedical engineering. Twenty or thirty now provide tagged degrees or have separate departments. The total number of enrolled students is close to 3000, of which 1500 are graduate students." Weed concluded that educational programs should aim for the following expertise: "the basic biomedical engineering research scientist, the technology interface engineering expert in health care delivery, and the biomedical design engineer for industry." Mylrea and Sivertson addressed the potential of biomedical engineering versus its reality in healthcare (Mylrea and Sivertson, 1975). They stated that, while biomedical engineering gained vast recognition, its application in healthcare did not meet the desired expectations. In this regard, they proposed the following requirements so as to expedite the synergistic interaction between engineering and healthcare: i) "Expanded and successful use of clinical engineers in health care institutions"; ii) "the development of relevant educational curricula and a continuum of medical engineering education"; and iii) "early involvement of biomedical engineering in the planning of health care delivery at Federal, State and district levels." To meet these requirements, the authors recommended that universities and colleges engage in comprehensive studies on the exact potentials of clinical engineers in order to formulate appropriate curricula and develop adequate educational resources. Henceforth, graduates of such programs will be equipped with the necessary skills and means to smoothly integrate as clinical engineers within the medical community. On the other hand, Schwartz and Long believed that "The Biomedical engineer has taken his place at the side of the physician and surgeon as an essential part of today's complex pattern of health care and preventive medicine and the research which leads to the successful development of improved methods for prevention, treatment, and repair of accident and disease." They further characterized the biomedical engineer as one being endowed with diverse specialization to fit in any of the three categories: i) Bioengineering, ii) Medical Engineering, and iii) Clinical Engineering (Schwartz and Long, 1975). The authors then quantified the results obtained from a survey analysis of biomedical engineering education performed jointly by the American Society for Engineering Education and the Engineering in Medicine and Biology group of the IEEE in 1974. The objective of this survey was to "identify all the engineering schools in the U.S. having Biomedical Engineering degrees, options or programs" so as to study the academic growth of biomedical engineering as a new career. This survey utilized a questionnaire that was sent to 222 engineering schools, and a summary of its major findings is presented in Table 1.

Kahn commented on the subject of biomedical engineering education for employment by industry by stating that despite the significant key roles that had emerged in the industry for trained bioengineers, there existed a number of shortcomings that precluded the latter from finding challenging and leadership jobs (Kahn, 1975). He argued that these shortcomings were partially due to the discrepancy between the level of development of the biomedical industry and the type of training received by the bioengineers, which is insufficient to qualify them to become effectual at handling the requirements of the anticipated teamwork. Subsequently, bioengineers were not found to be the most effective people at '*process product engineering*' since neither hardware orientation

Table 1. Summary of reported results from Schwartz and Long, 1975

Total U.S. engineering schools surveyed (early months of 1974)	**222**
Schools having degrees or programs in BME	121
Schools with no programs or degrees in BME	76
Schools who did not respond	25
Schools awarding degrees in BME	**49**
B.S. degree	25
M.S. degree	37
Ph.D. degree	38
Schools offering options or programs in BME in which the student received some other engineering degree	88
BME student enrollment for the 1973 fall semester	**3769**
B.S. degree	1530
M.S. degree	1306
Ph.D. degree	933
BME degrees awarded between 1965 and 1973 fall semester	**2889**
B.S. degree	574
M.S. degree	1424
Ph.D. degree	891

nor management was a major part of their training or experience. Kahn recommended that in order for the bioengineers to be team leaders within an industrial setup, educational programs have to be reengineered in such a way that "the areas of teamwork and the management of people and programs" become an integral part of biomedical engineering training. He added that further training is also needed in the "technical areas of the interface of body tissues with materials and electrical current". In a paper entitled "*Organization and Function of a Hospital Biomedical Engineering Internship Program*", which describes the development of an internship program between St. Vincent Hospital, Worcester, MA, USA, and Worcester Polytechnic Institute, WPI, Worcester, MA, USA, Peura *et al*. stated that there existed a growing need for biomedical engineers to work in the clinical environment. The authors expounded that based on a previous survey conducted by Long (1974) on the schools of engineering in the U.S. "approximately 20 percent of the programs have either a required or optional internship or residency program with a hospital". As such, the authors went on to demonstrate the advantages and importance of their innovative and interactive internship program, whose primary objective "is the education of the student through problem solving in the hospital environment under close faculty-physician supervision." Accordingly, at the end of his/her undergraduate education, the student is awarded a B.S. degree "on the basis of demonstrated competence, rather than on the basis of the traditional accumulation of academic credits." The authors concluded that "the internship program approach is an excellent educational format not only for the students training in biomedical engineering, but also for those entering other disciplines." According to the authors, the *students* attain general benefits from this "*Internship Program*" in that they: i) "develop various levels of foresightedness, sophistication, self-confidence, analytical competence, creative imagination, perseverance and managerial skills", ii) are helped "to direct their orientation toward further education at both the undergraduate and graduate levels", iii) "have learned to identify what they need to know", and iv) initially, without any clear career path, "have formalized specific plans for additional education in biomedical engineering or employment in the health-care field." The authors added that these benefits could be extended to the *faculty project advisors* by being exposed to "new applications of engineering in medical fields." As for the *hospital*, this "*Internship Program*" proved profitable "in terms of useful and practical work (i.e., the technical base of the hospital has been broadened)… Major equipment at WPI has become available for medical use". The last sampled paper in this early special issue of the *IEEE Transactions on Biomedical Engineering* is entitled "*A Clinically Oriented Bioengineering Program for Undergraduates*" (Detwiler *et al*., 1975). In this paper, the authors describe their experience in launching an undergraduate program in Bioengineering at Carnegie-Mellon University, CMU, Pittsburgh, PA, USA. According to the authors, this program is an outgrowth of the "well-established graduate research activities" of the said academic institution. It "supplements the basic curriculum of an Engineering department with courses in the life sciences, clinical and instrumentation laboratories, and a hospital internship" – thus producing a *hybrid engineer*. The stated objectives of the program were "*to provide the student with a familiarity with engineering applications in the medical field and to encourage the ability to work cooperatively in the clinical environment*." The authors offered a word of advise to the prospective bioengineering graduates that if they are to be employed as 'Clinical Engineers', they have to pursue professional "growth and evolution" throughout their careers so as to cope with the "fast-changing technology" and be well-fit for the "unpredictable employment market". They added that to be able to work in "a very special, non-engineering environment" the bioengineer must develop his/her "experience, language, background knowledge and organizational skills." The authors concluded their paper by stating that "our success in the program must be measured by how many graduates successfully pursue careers in the biomedically related professions either in industry, or in the hospital environment, or in the university, and not by their achievements in the engineering profession."

In 1981, Potvin *et al.* conducted a quantitative study around biomedical engineering education (Potvin *et al.*, 1981) similar to the one performed by Schwartz and Long in 1974 (Schwartz and Long, 1975). The Education Committees of four societies supported Potvin's study, namely: i) the Biomedical Engineering Division of the American Society of Engineering Education, ii) the IEEE Engineering in Medicine and Biology society, iii) the Biomedical Engineering Society; and iv) the Alliance for Engineering in Medicine and Biology. This study consisted of a modified survey questionnaire from the one used in 1974 so as "to broaden the acquired information to include biomedical engineering courses and textbooks used, and employment or advanced training". The modified questionnaire, which was sent to 251 engineering schools in the United States, touched on enrollment, courses, and degrees data covering the academic year 1979-1980, and employment data from the academic year 1978-1979. Table 2 summarizes the major findings of this survey.

According to this study, the number of schools offering B.S., M.S., and Ph.D. programs in biomedical engineering increased, without exception, within the five years that preceded the study; a fact that was reflected in the increase of total enrolment from 1769 to 4158 students.

In 1982, White and Plonsey, in their argument whether or not biomedical engineering education produced real engineers, stated that "biomedical engineering education must address a wide spectrum of knowledge… it must concentrate on basic science and technology, as well as developing attitudes of creativity, ingenuity, and innovation that will allow the student to apply technical knowledge to the non-traditional field of medicine" (White and Plonsey, 1982). The authors surveyed the curricula of 29 institutions of higher learning offering a degree program or an option in biomedical engineering during the academic year 1980-1981. The main aim of the study was to quantify the overlap/differences between existing biomedical engineering curricula and the older discipline of electrical engineering. Its hypothesis was to quantify the amount of reduction in engineering course work resulting from the inclusion of life sciences within the biomedical engineering programs, and to determine whether the amount of life sciences course work

Table 2. Summary of reported results from Potvin et al., 1981

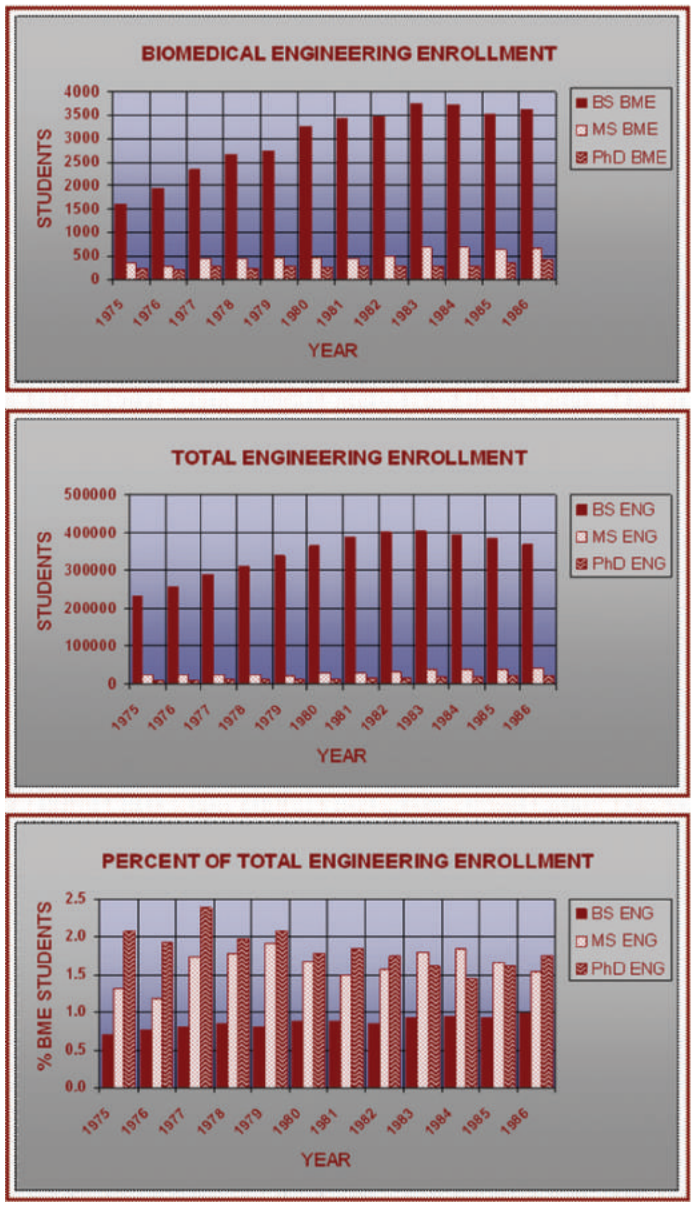
Total U.S. engineering schools surveyed (academic year 1979-1980)	**251**
Schools having degree programs in BME	71
Schools having official minor or option programs in BME	35
Schools with no programs or degrees in BME	107
Schools who did not respond	38
BME Programs accredited by the Accreditation Board for Engineering Training/Engineers Council for Professional Development	**22**
Schools awarding degrees in BME	**71**
B.S. degree	37
M.S. degree	48
Ph.D. degree	41
Schools offering options or minors in BME in which the student received some other engineering degree	**35**
B.S. degree	41
M.S. degree	42
Ph.D. degree	34
BME student enrollment for the 1979-1980 academic year	**4158**
B.S. degree	2859
M.S. degree	830
Ph.D. degree	469
BME degrees awarded during the academic year 1978-1979	**820**
B.S. degree	464
M.S. degree	249
Ph.D. degree	107
Placement of the BME graduates of the academic year 1978-1979	**630**
Industry	253
Government	23
Academia	35
Hospitals or clinics	66
Medical school	100
BME graduate schools	96
Other graduate or professional schools	57

sufficed. The authors emphasized that the uniqueness of biomedical engineering is attributed to the resourceful combination of technology and life science parameters, both of which are constantly evolving. They added that the core of knowledge that the field of Biomedical Engineering upholds can be introduced in undergraduate programs together with practical training. At the end of their paper, White and Plonsey drew the following conclusions: i) "the amount of life science included in biomedical engineering is adequate to provide for the needs of both students who do not desire further education and those who do"; ii) "there is indeed enough training in engineering principles to produce highly qualified engineers"; and iii) "undergraduate biomedical engineering education is both valid and desirable".

In a research study entitled '*Status and Trends in Biomedical Engineering Education*' and published in 1989, Pilkington *et al.* reported that there has been a steady growth in biomedical engineering since its inception, and that it has gained "acceptance as body of knowledge soundly based in both the biomedical and engineering disciplines" (Pilkington *et al.*, 1989). They expounded on the steady state of the positive correlation between the number of degrees granted and the available number of career opportunities; as well as on the increased awareness of employers towards the tangible training and capabilities of biomedical engineers. The authors reported the actual number of students enrolled both in engineering and biomedical engineering between 1975 and 1986. These results are graphed in Figure 1. They also reported that 18 programs in biomedical engineering were accredited by the Accreditation Board for Engineering and Technology, Inc., ABET, Baltimore, MD, USA. Pilkington *et al.*, concluded that "the status of biomedical engineering today can be best described as satisfactory and improving … Supply and demand are in good balance, with employment possibilities adequate and of satisfactory quality."

Another milestone in biomedical engineering education was released in 1999 by the *International Journal of Engineering Education*. This special issue consisted of 13 papers including two editorials. According to the Guest Editor, J.G. Webster, "Many papers in this issue describe alternative approaches to encourage students to find information, develop a systems approach, work with biologists, consider bioethics, develop professionalism, perform design, and develop the skills required to solve biomedical engineering problems" (Webster, 1999). Five of these papers were found relevant to this chapter and are highlighted herein. King, in his paper, attempted to draw the attention of manufacturers of biomedical devices and educators in the field to the important aspect of design within undergraduate biomedical engineering curricula in the United States (King, 1999). Sixty nine academic programs in biomedical engineering were studied and at least 21 of which were found to be accredited by ABET; thereby, implying that these accredited programs must have had a significant design content. King further identified "internships, the new accreditation criteria, and private and governmental support of research and design activities in biomedical engineering programs" as the current approach that will have a positive impact on the future of biomedical engineering programs. He concluded that it is high time for financial and social scenarios to be guided towards more "direct involvement of biomedical engineering students and faculty in the growth of the medical device and design industry". King utilized the biomedical engineering curriculum at Vanderbilt University, Nashville, TN, USA, as a supportive model in his paper. Viik and Malmivuo, in their paper, presented the survey results of an investigation pertaining to the employment status-quo of biomedical engineering graduates holding a Master of Science degree from the Ragnar Granit Institute at Tampere University of Technology, Tampere, Finland (Viik and Malmivuo, 1999). The survey sampled 267 biomedical engineers who graduated between 1976 and 1997 and out of which 77% responded to the questionnaire. The survey pivoted around the following questions: i) "*How soon after their graduation did engineers acquire a job?*"; ii) "*Where did they find a placement and with what type of job description?*"; iii) "*How did their job description correspond with their education at TUT?*"; and iv) "*Did their job description involve BME?*". The following outcomes were then reported: i) 90% of the respondents found their first job within three months; ii) 95% of the respondents were employed on a full-time basis with 57% located in the Tampere area; iii) 68% of the respondents reported that the tasks of their first job corresponded '*to a large extent*' with their education; and iv) 37% of the respondents reported that the relation of job description to biomedical engineering corresponded to being '*fully or almost fully*', while 10% corresponded to being '*to some extent*'. Another paper by Schreuders and Johnson described "*A Systems Approach for Bioengineering*" (Schreuders and Johnson, 1999). The authors stated that "Bioengineering … arose from the need to create and modify systems that include one or more living elements, whether the elements are bacteria, humans, or entire ecosystems". Accordingly, the authors proclaimed that "a *critical goal* of bioengineering education is the introduction of the student to some of the techniques necessary to apply engineering problem solving to living organisms and systems". They added that "a classic approach to engineering problem solving is reticulation, breaking the object of study down into a series of networked components. The identified components are then examined and the implications of their arrangement studied… The crux of the systems approach is that description of complex systems requires understanding of the nature of the individual components, and how they interact with each other." In this sense, the authors distinguished 'Bioengineers' - biomedical or biological - from other engineers by the fact that "they must consider not just the abiotic components of a system but the biotic components as well." They have then used this distinctive feature to support the hypothesis, which states that "bioengineering students must learn to apply classical engineering concepts in profoundly new ways and to a breadth of biological systems not found

Figure 1. Enrollment in the United States between 1975 and 1986 at the BS, MS, and Ph.D. levels: (Top) Number of students enrolled in biomedical engineering programs; (Middle) Number of students enrolled in all engineering programs; (Bottom) Percent biomedical engineering student enrollment of total engineering enrollment. Data compiled from Pilkington et al., 1989.



in any other engineering discipline.” Subsequently, the authors proposed the ‘*systems approach*’ as a teaching paradigm for bioengineering students; whereby the students are “introduced to biological systems through a series of examples in which interactions between living things differ substantially from other elements of their engineering design”. They went on to say that “we must demonstrate that a living material and its environment are inextricably linked, that they must be considered as a system". They then concluded by stating that "the students should be encouraged to make the transition between a theoretical and fundamental understanding of this systems approach". Coger and de Silva, in a paper entitled "*An Integrated Approach to Teaching Biotechnology and Bioengineering to an Interdisciplinary Audience*", described the development and implementation of a graduate-level course in Biotechnology and Bioengineering at the University of North Carolina at Charlotte, UNC, Charlotte, NC, USA (Coger and de Silva, 1999). This course, which was also open to advanced undergraduate students, was designed, in the absence of a formal bioengineering program, to introduce engineering, biology, physics, and chemistry students to both fields-Biotechnology and Bioengineering-at the same time. The philosophy behind the introduction of such a course, according to the authors, was that "the next generation of biotechnological advancements will continue to require interdisciplinary communication among engineers, biologists, and physical scientists." They added that "likewise, in all aspects of bioengineering, biology helps provide the framework for understanding which questions and problems are important, while the engineering is critical to developing effective solutions." In this regard, five *learning objectives* were introduced and were continually assessed in the progress of the course throughout the semester. The objectives were: i) "Understand key science and engineering principles that are fundamental to biotechnology and bioengineering", ii) "Advance from the *understanding* of these key principles to their *application* in current Biotechnology and Bioengineering innovations", iii) "Communicate effectively–through written and oral communications–with a cross disciplinary audience", iv) "Effectively participate in interdisciplinary teams", and v) "Critically analyze biotechnology/bioengineering innovations for the need that it meets and its overall impact." The methods of assessment included cooperative learning exercises, homework, exams, and final projects. Furthermore, five topics constituted the cornerstones of this course, and were selected on the basis of achieving a balance between its breadth and depth. The topics were: i) "The Engineering and Biology of Motion", ii) "Bioremediation in Environmental Engineering", iii) "Genetic Engineering", iv) "Bioengineering and the Cardiovascular System", and v) "Immune Response to Engineered Devices". In the last of these sampled papers, entitled "*Teaching Ethical Issues in Biomedical Engineering*", Monzon stated that there are still many places around the globe where biomedical engineering as a profession "still awaits formal recognition" (Monzon, 1999). The author attributed part of this delay to the "intrinsically multi and interdisciplinary characteristics" of this field. He added that this delay "is aggravated by the lack of precise ethical rules that delineate and delimit the professional responsibility of biomedical engineers." The author proceeded to elaborate on some of the ethical issues that are fundamental to biomedical engineers. This was then supplemented by ways of integrating these ethical issues in biomedical engineering curricula. The paper was concluded by delineating the topics in ethics that ought to be covered in a biomedical engineering program.

The year 1999 also witnessed the formation of the Vanderbilt - Northwestern - Texas at Austin - Harvard/MIT Engineering Research Center, VaNTH-ERC, Nashville, TN, USA, which was sponsored by the National Science Foundation, NSF, Arlington, VA, USA. The function of this center was to improve '*the short- and long-term outcomes of biomedical engineering education*' at different academic levels with particular emphasis on undergraduate education (Linsenmeier *et al.*, 2002; Cordray *et al.*, 2003). Soon after, the VaNTH-ERC launched an interactive website to provide a productive medium for "*Uniting educators and engineers, in industry and academia, to develop curricula and technologies that will educate future generations of bioengineers*."

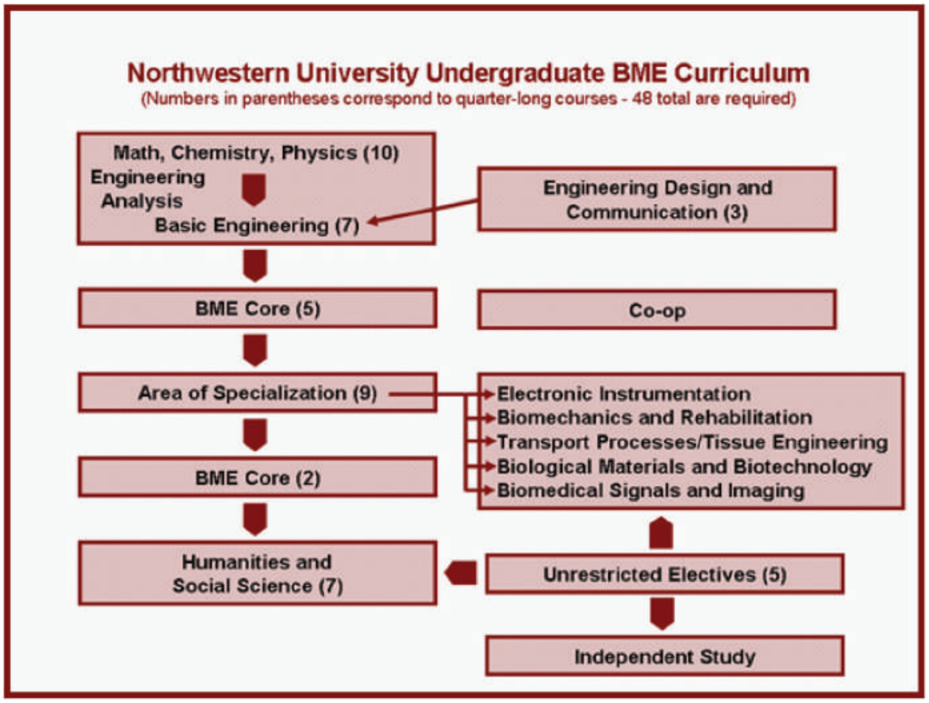
(Anonymous, 1999). Linsenmeier *et al. commented* that amongst the many important constituents of this website is: i) a listing of '*core content*', rather than '*core courses*', for undergraduate programs in biomedical engineering, and ii) a set of recommendations for the creation of biomedical engineering curricula in terms of both content and pedagogy (Linsenmeier *et al.*, 2002). In its early years, the VaNTH-ERC for Bioengineering and Educational Technologies recommended that in order to create such curricula, considerations should be made to a number of issues that fall under the following umbrellas (Anonymous, 1999): i) philosophical underpinnings and assumptions; ii) steps to creating a curriculum; iii) industry requirements for bioengineers; iv) bioengineering content; and v) basic bioengineering. To help resolve many of the aforementioned content issues, the VaNTH-ERC created a '*Strawman Curriculum*' for undergraduate biomedical engineering programs (Anonymous, 1999). VaNTH-ERC, as well, published a web-based multi-step survey entitled '*Delphi Study*' to determine the key concepts required to constitute the foundation or '*core*' of undergraduate biomedical engineering curricula (Anonymous, 1999; Gatchell *et al*., 2004). The Delphi Study consisted of 80 questions within 19 categories that included "eleven biomedical engineering domains, four biology domains, physiology, engineering design, and mathematical/scientific pre-requisites" (Gatchell *et al*., 2004). Gatchell *et al.* commented that they "expect that the results of this survey will aid academia in identifying the fundamental concepts that undergraduate 'biomedical engineers' should know and should facilitate the industrial hiring of a larger percentage of our undergraduates by further establishing the identity of the biomedical engineering field" (Gatchell *et al*., 2004). A flowchart of the undergraduate biomedical engineering curriculum at Northwestern University, Evanston, IL, USA, a member of the VaNTH consortium, is presented in Figure 2. Further discussion about the VaNTH-ERC for Bioengineering and Educational Technologies is presented in Section 1.5.1.

In 2000, the first international summit meeting on biomedical engineering education was instantiated under the auspices of the Whitaker Foundation, Arlington, VA, USA (Anonymous, 2006b). This meeting amassed a body of important information on active academic programs in biomedical engineering at that time, and its objectives were to assist universities offering biomedical engineering curricula to address futuristic needs, ranging from academic to healthcare, via the design and modification of these curricula. Following its summit meeting, the Whitaker Foundation published on its summit website the outcomes of the underlying workshops pertaining to key areas for biomedical engineering curricula, which included (Anonymous, 2006b):

1. Real biomedical classroom experiences, basic science foundations, engineering foundations, biomedical engineering laboratories, and societal issues and ethics.
2. A number of specific curricula in biomedical engineering, pivoting around two areas – basic and advanced:
    a. **Basic areas:** biomechanics, bioinstrumentation, biosystems, cell/molecular engineering, and biomaterials.
    b. **Advanced areas:** functional genomics, Microengineering in a biological world, cell and tissue engineering, computational biology, and biological and biomedical imaging.

Katona expressed his opinion on the outcomes of the Whitaker Foundation's summit meeting by stating that "the participants concluded that developing a single, '*optimal*' program is neither possible nor desirable. Programs need to define their own objectives, taking into account current and planned institutional strengths, and then pursue these goals vigorously and imaginatively. Most agree that programs must have rigor both in engi-

Figure 2. A sample flowchart of the VaNTH-ERC undergraduate biomedical engineering curriculum implemented at Northwestern University, Evanston, IL, USA



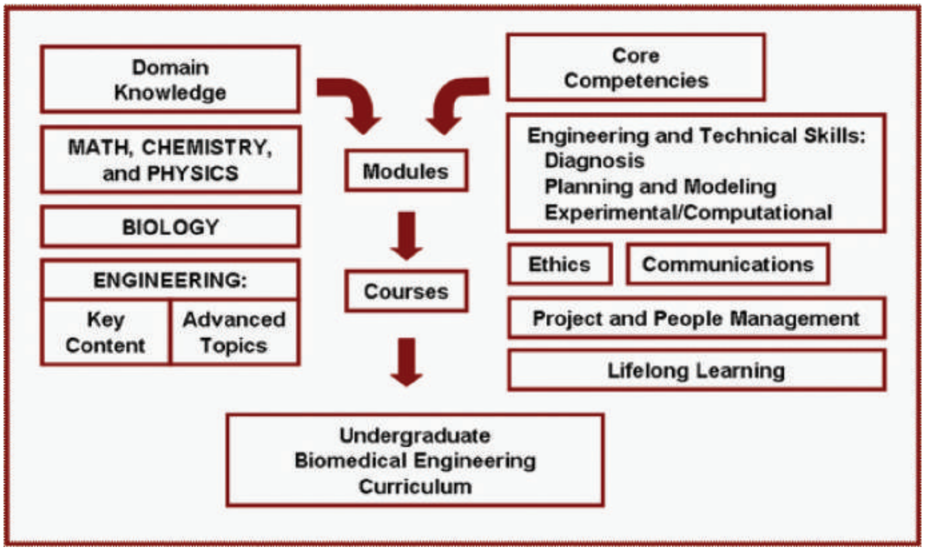
neering and the life sciences and that integrating the two components must occur throughout the curriculum" (Katona, 2002).

In a review of the recent advances in learning sciences and learning technologies and their respective roles in biomedical engineering education, Harris *et al.* accentuated that the challenges facing biomedical engineering education encompass all components of the educational process, namely faculty, students, and employers of graduates (Harris *et al.*, 2002). The authors affirmed that instructional paradigms in biomedical engineering could be re-evaluated via the '*How People Learn*' framework provided by the new advances in the learning sciences. In their study, Harris *et al.* demonstrated that learning environments should be: i) "*learner centered* in the sense that they take into account the knowledge, skills, preconceptions, and learning styles of the learners"; ii) "*knowledge centered* in the sense that they help students learn with understanding by thinking qualitatively, organizing their knowledge around '*key concepts*' or '*big ideas*' of the discipline and understanding the conditions under which different aspects of their knowledge are applicable"; iii) "*assessment centered* in the sense that they provide frequent opportunities for students to make their current thinking visible so their understanding can be refined as needed"; and iv) "*community centered* in the sense that they foster norms that encourage students to learn from one another, plus encourage faculty to do likewise." The authors proceeded by stating that learning technologies could optimize the inception of such an environment. The study concluded that advancements in learning sciences and learning technologies combined with reform in engineering education are to be considered as advantages for educators in biomedical engineering to benefit from when designing and implementing new learning systems. It is worth noting that the paper reported the existence of 21 undergraduate programs in biomedical engineering within the U.S. that were accredited by ABET at that time.

In 2003, under a theme section entitled '*New Directions in BME Education*', the *IEEE Engineering in Medicine and Biology Magazine* hosted 16 articles; seven of which were sampled to be included in this chapter. Linsenmeier focused in his paper on the methods to be adopted in addressing the needs of the industry as well as the boundaries within which a common undergraduate curriculum in biomedical engineering can and should exist (Linsenmeier, 2003). He stated that "the increase in the number of positions in industry for biomedical engineers means that industry is a constituency that should be consulted about the curriculum". He added that since the main thrust of a successful undergraduate curriculum in biomedical engineering should be focused on preparation for industry, the following four questions are in order: i) "*What perception does industry have of biomedical engineers?*"; ii) "*What are the needs of industry?*"; iii) "*What niches will biomedical engineers occupy at the B.S. level?*"; and iv) "*Which industries should we consider in our analysis of needs?*" In this context, Linsenmeier subdivided the bioengineering/biomedical engineering industry into one that includes the biomedical instrumentation companies, another that encompasses the pharmaceutical and drug delivery-oriented companies, and the other that includes a group of companies engaged in tissue engineering and various cell-based therapies. Afterwards, the author reflected on the fact that, according to the VaNTH curriculum project, biomedical engineering programs should concur at least on what biomedical engineers should know and not necessarily on the whole curriculum. He stated that "We are seeking a core set of knowledge and skills that we call '*key content*'." He then added that "It is also important to consider the "*core competencies*" as a complementary side of a biomedical engineering curriculum. Figure 3 illustrates Linsenmeier's perspective of a two-sided complementary biomedical engineering curriculum comprising of '*Domain Knowledge*' and '*Core Competencies*'. Linsenmeier reported that 24 programs in biomedical engineering were accredited by ABET at the time.

Brophy conjectured, in another paper, that "Innovations in learning sciences and technology are opening new opportunities for designing and implementing effective learning materials that can be shared between bioengineering instructors" (Brophy, 2003). He insinuated that with technology, a wide spectrum of web-based resources could be deployed in order to enhance the abilities of students for self-regulated learning. The author then reported that, along the same lines, the VaNTH-ERC was investigating methods to design and validate learning materials for bioengineering education and establishing a technological foundation that would support the reusability of these materials based on proper pedagogical principles. Brophy added that the VaNTH has defined a design process that benefited from the current theories of learning sciences and best practices in engineering education. Subsequently, a multidisciplinary specialized design team consisting of "domain experts, learning scientists, assessment experts, and technology experts" was formed for the purpose of redesigning bioengineering education. The author, referring to this design teams, stated: "Their decisions about what and how to teach their content has been guided by a learning cycle to support inquiry learning and the how people learn (HPL) framework, which identifies important principles of effective learning environments". He further emphasized the use of *challenge-based instruction* (CBI) in organizing course content, which he believed that, together, "The HPL framework and CBI provide structure for categorizing the important features for an engineering learning environment". He added that the success of this learning environment is contingent on a series of factors that "define key steps in planning a module of instruction and an entire course that uses a collection of challenges and learning activities." These factors were: i) "iden-

Figure 3. The two-sided complementary biomedical engineering curriculum comprised of 'Domain Knowledge' and 'Core Competencies'. Adapted from Linsenmeier, 2003.



tifying course-level learning objectives"; ii) "identifying unit-level learning objectives"; iii) "identifying and prioritizing course content to meet these goals"; iv) "defining assessment items to verify achievement of these goals"; v) "defining effective challenges that motive students and set up meaningful inquiry that meet the learning objectives"; and vi) "defining learning materials and activities that support learning with understanding." A comprehensive description of the HPL framework is provided in a manuscript by the National Research Council, National Academy of Sciences, Washington, DC, USA, entitled "*How People Learn: Brain, Mind, Experience, and School*" (Bransford *et al.*, 1999). In their paper, Cordray *et al.* described the implementation of a '*counterfactual model of causal analysis*' to appraise the '*value added*' of the project-level assessment and the evaluation activities made by the VaNTH (Cordray *et al.*, 2003). The authors concluded that: i) "Based on a counterfactual model of causal analysis, VaNTH investigators have been encouraged to use experimental and quasi-experimental research designs to estimate the '*value added*' for their innovations"; ii) "By applying the logic, principles, and criteria of a counterfactual causal model, as opposed to a '*cookbook*' application of designs and statistical procedures, VaNTH investigators have begun to develop a firm knowledge base about the relative effectiveness of their HPL-inspired innovations"; iii) "It is possible to assess and evaluate, in a quantitative way, the relative effects of educational innovations in engineering courses"; iv) "A broader assessment of the HPL model underlying VaNTH can be undertaken by systematically looking across studies within VaNTH"; and v) "By implication, the knowledge gained about engineering education from assessment and evaluation efforts within VaNTH should be much greater than the sum of its parts." Riesbeck *et al.*, in agreement with Brophy (2003), reported that several learning technologies have been established by the VaNTH-ERC for Bioengineering Educational Technologies to advocate the usage of '*Web-based interactive environments*' that promote critical reasoning skills in engineering learning framework (Riesbeck *et al.*, 2003). Within this context, the authors described two applied technologies, the *Indie* and *SASK* tools.

The *Indie tools*, whose name is an acronym for investigate and decide, "are for authoring and delivering challenge-based scenarios where learners have to investigate a situation, perform (simulated) experiments, and use the resulting data to argue for and against possible hypotheses and courses of action." Whereas the *SASK tools*, whose name is an acronym for '*Socratic ask*', "are for authoring and delivering question-driven Socratic dialogs to foster critical reflection by learners engaged in a problem-solving challenge." Employing a bottom-up design approach, the aforementioned tools were developed to support "challenge-based learning activities" that have proven "effective for long-term learning". In a paper entitled "*An Industry Perspective on Senior Biomedical Engineering Design Courses*", Fries presented a '*Win-Win-Win*' biomedical engineering relationship amongst the students, the university, and the industry, whereby all are beneficiaries (Fries, 2003). Fries expounded on the involvement of the industry in senior biomedical engineering design courses, and then provided a summary of a four-year partnership endeavour among Datex-Ohmeda, Louisville, CO, USA, Vanderbilt University, Nashville, TN, USA, and VaNTH-ERC in addition to the cooperative (co-op) and summer internship programs with Marquette University, Milwaukee, WI, USA, and the University of Wisconsin, Madison, WI, USA. He further delineated the benefits of such an endeavor as follows: *Students* i) "gain the knowledge they will need to succeed in industry after graduation"; ii) "get the experience of working within an industrial product development program"; iii) "use the knowledge they have gained at the university in a real-world situation"; and iv) "get paid for working as co-ops or interns". *The university* i) "learns more about how the industrial product development process works"; ii) "learns what topics are important to that product development process"; iii) "gets active participation by industrial personnel"; and iv) "receives donations in the form of time, equipment, and money". *Industry* has i) "input on what students are learning and how that will prepare them for their potential positions"; ii) "the opportunity to identify students as potential employees"; iii) "students working on projects that the company can use in their own product development"; and iv) "students working for them for a short time to assist in their product development". The author concluded by speculating on the possibility that the involvement of biomedical companies and institutions of higher learning in this kind of program might result in a significant advancement in biomedical engineering as well as in healthcare. Another paper within this series addressed the *University-Industry Partnerships in Biomedical Engineering* (Waples and Ropella, 2003). Waples and Ropella reported that Marquette University was able, with the support of a 1995 Whitaker Foundation Industrial Internship Grant, to establish the largest *cooperative education* and *industrial internship* program in biomedical engineering in the United States. The focus of this paper was to describe the vital activities that are necessary to establish and maintain such a promising program. In this context, the authors emphasized the need of three fundamental elements to establish this endeavor: i) "a professional development process weaved into a unique freshman/sophomore curriculum"; ii) "proactive recruitment of cooperative and internship opportunities"; and iii) "an infrastructure to sustain the university-industry partnerships and monitor the experiences of both students and industry participants". Subsequently, the authors reported four main outcomes of their study: i) "The investment of personnel, time, and money for the past eight years has produced industrial partnerships with over 30 companies and additional yearly interactions with over 175 companies throughout the United States"; ii) "The return of our investment has been a continued increase in the students and employers participating in the cooperation program"; iii) "Our students have experienced greater success in full-time placement based on the increased participation with employers recruiting at Marquette University"; and iv) "We have benefited from increased enrolments in our undergraduate program". Furthermore, the paper delineated the cumulative benefits to all stakeholders by stating that: *Participating students* i) "work as engineering professionals"; ii) "gain valuable engineering and business experience"; iii) "apply engineering concepts to real-world problems"; and iv) "tend to be more focused on their career choices after participating in a cooperation or internship opportunity". *Employers* i) "have the opportunity to train potential long-term employees"; ii) "capture the attention of motivated, talented biomedical engineers"; iii) "obtain visibility at the university"; and iv) "ultimately lower their turnover and training costs". *The Biomedical Engineering Department* i) "benefits from industrial partnerships through increased student satisfaction"; ii) "improved student training"; iii) "novel education programs"; iv) "job placement for graduates"; and v) "research collaboration." Enderle *et al.*, in the last of these selected papers, expounded on '*The ABCs of Preparing for ABET*'. Written by fully trained ABET evaluators, the paper proposed guidelines for planning, implementing, and accrediting biomedical engineering programs (Enderle *et al.*, 2003). The authors first denoted that "ABET, Inc. is recognized by the U.S. Government as the accreditation organization for college and university programs in applied sciences, computing, engineering, and technology". Then they continued to emphasize that the main functions of ABET are to: i) set the goals and objectives for accreditation; ii) evaluate the process; and iii) constantly release improvement guidelines. The authors further added that the student, faculty, facilities, institutional support, and financial resources are the essences for program evaluation. Additionally, Enderle *et al.* reported that the new program review process of ABET, which is recognized as '*Engineering Criteria 2000 - EC2000*' or simply '*Engineering Criteria – EC*', has provoked "a change from a prescriptive evaluation to one based on program-defined missions and objectives with an emphasis on outcomes". Subsequently, as of the year 2001, this new Engineering Criteria had to be implemented by all pertinent programs aiming for ABET accreditation. The authors, interestingly, recommended that "Since the ABET criteria provide only a minimum set of requirements, 'Biomedical Engineering' programs should not use this as a target but rather set their goals higher by including state-of-the-art and real-world experiences that enrich the curriculum" (Enderle *et al.*, 2003). Details about the ABET's '*EC2000 Criterion 3 - Program Outcomes*' and '*Program Criteria*' pertaining to bioengineering and biomedical engineering are provided in Section 1.5.3 The Accreditation Board for Engineering and Technology - EC2000.

The Whitaker Foundation held, in March 2005, its second international summit meeting on biomedical engineering education. This meeting was also the last before the foundation officially came to a closure in 2006. This last summit, in accordance with the first meeting, was intended to help universities in designing and modifying their programs in biomedical engineering in order to be readily prepared for upcoming challenges (Anonymous, 2006b). Two complementary educational philosophies constituted the corner stones to the planning of the two summit meetings, one made by the Whitaker Foundation while the other by ABET. Both philosophies are reported in Section 1.5 Bioengineering/Biomedical Engineering Curriculum Philosophies.

In 2002, a historical review of the Whitaker Foundation, established in 1976, was presented by Katona who also delineated the foundation's goals and a number of its programs (Katona, 2002). He also addressed the future of Biomedical Engineering subsequent to the closure of the foundation in 2006. The author reported that, from 1976 till 2002, the Whitaker Foundation granted over 700 million USD; and he expected that an additional 100 million USD would be granted, between 2002 and 2006, before the closure of the foundation.

Katona enumerated the following contributions provided by the Whitaker Foundation: i) support, through the Biomedical Engineering Research Grant program, to over 1300 investigators; ii) 30-40 new doctoral fellowships were typically granted every year, beginning 1991; and iii) bestowed awards ranging from 750,000 USD to 18 million USD to each of 75 institutions. The author further commented that the increased spending level from 1991 to 2003, the year that marked the last of the "*multiyear awards*", has expedited the formation of formal educational programs at universities in addition to the erection of new facilities. Katona concluded his paper with a strong affirmation to the speculation of "whether the field of biomedical engineering will continue to prosper after Whitaker funding ceases".

In 2006, a paper entitled '*Core Elements of an Undergraduate Biomedical Engineering Curriculum – State of the Art and Recommendations*', written by Linsenmeier and Gatchell, showed that by the spring of the same year, 37 undergraduate programs in biomedical engineering and bioengineering within the US had been accredited by ABET (Linsenmeier and Gatchell, 2006). The authors' objective behind this paper was "to identify elements of undergraduate biomedical engineering and bioengineering curriculum that should be common across universities" through the implementation of the Delphi approach and via the analysis of the 37 accredited programs by ABET. The outcomes of their study asserted that no two programs were identical; yet, among the studied programs there existed a 75% overlap in certain required courses, which were functionally "*regarded as the core*". Furthermore, the data obtained from the Delphi study implied that the core should be expanded to encompass a few additional courses, thus, leaving 18.2 ± 9.6 credit hours to be allocated for specialization courses as implemented by the accredited programs. At the end of their paper, the authors recommended the following: i) "We imposed a limit of 78 credit hours for the core, allowing 18 hours of flexibility in specialization courses"; ii) "Engineering, math and science then comprise 96 credit hours, three quarters of a typical 128 hour curriculum"; and iii) "Within the 78 units we also recommend two of the following three courses: signal analysis, organic chemistry, and thermodynamics. We prefer to recommend all three".

Nagel *et al.*, in 2007, described in details the medical and biological engineering and science within the higher educational system in Europe (Nagel *et al.*, 2007). The authors began their manuscript with an introduction of the *Bologna Declaration* that was signed in 1999. This was followed by a delineation of its objectives, which after their implementation had led to the foundation of the *Bologna Process*. The demand for the establishment of a *European Higher Education Area* (EHEA) was one of these objectives; knowing that, as of 2004, a time when the European Union (EU) encompassed 25 member countries, the number of European countries participating in the *Bologna Process* reached 45. The authors reported that, based on the EU list of priorities, the Bologna movement has prompted the *European Medical and Biological Engineering and Science* (MBES) community to develop their '*Higher Education Area*' by i) "harmonizing the educational programs"; ii) "specifying minimum qualifications"; and iii) "establishing criteria for an efficient quality control of education, training, and lifelong learning". The MBES adopted these drafted guidelines as their target objectives, specifically to "establish a general European consensus on guidelines for the harmonization and accreditation of high-quality MBES programs and for the certification and continuing education of professionals working in the healthcare systems". Subsequently, more than 200 institutions of higher learning in Europe were reported to offer academic programs in MBES at the three-levels of higher education - bachelor, master, and doctoral levels. Interestingly, the authors commented on the lack of international coordination related to "contents and required outcome qualifications".

Nonetheless, they stated that the interactions in biomedical engineering education between Europe and the United States have been strong despite the differing educational environments. They expounded that while in some European countries the government takes full control of the higher educational system, in the United States it is the universities that have full autonomy. Furthermore, the authors drew attention to two main deficits within the European higher educational system; the first being that Europe has not had the opportunity to benefit from funds, similar to those provided by the Whitaker Foundation, to introduce new biomedical engineering programs and research; and the other is that Europe has not been endowed with a generally recognized accreditation agency, as ABET, that would take charge of the many aspects of quality assurance in higher education. The authors proceeded by stating that beginning in 1999, a Europe-wide consortium has been i) "engaged in projects aiming at creating a comprehensive survey of the status of MBES education and research in Europe"; ii) "charting the MBES community"; iii) "developing recommendations on harmonized MBES education, training, and certification"; and iv) "establishing criteria for the accreditation of MBES programs in Europe". Subsequently, a Europe-wide participation project 'BIOMEDEA', chiefly sponsored by the International Federation for Medical and Biological Engineering, IFMBE, Zagreb, Croatia, was initiated in 2004 so as to realize the above said objectives. The authors reported that BIOMEDEA was advancing in a productive manner and that 80 European academic institutions have participated in the three meetings that had taken place by that time. In this context, the authors reported that agreements have been established on i) the "Criteria and Guidelines for the Accreditation of Biomedical Engineering Programs in Europe" and ii) a "European Protocol for the Training of Clinical Engineers." The authors then concluded that "The evolving EHEA will substantially influence the development of educational aspects of medical and biological engineering and sciences."

1.5. BIOENGINEERING/ BIOMEDICAL ENGINEERING CURRICULUM PHILOSOPHIES

Given the substantial evolution in biomedical engineering/bioengineering education and its global proliferation over the past five decades, as has been comprehensively delineated in the previous section, attention is now directed towards three major philosophies that are considered the cornerstones that constitute the state-of-the-art reference to authorities who intend to launch or reform bioengineering/biomedical engineering curricula. These philosophies are presented herein:

1.5.1. The VaNTH-ERC for Bioengineering and Educational Technologies

When addressing the '*Vision and Overall Strategy*' of VaNTH-ERC, Harris explained that "VaNTH defined its mission to be an ERC that would unite educators and engineers, in academia and industry, to define and develop bioengineering education for the future" (Harris, 2001). The VaNTH ERC Education Mission is stated herein in details (Anonymous, 1999):

"VaNTH ERC is dedicated to recruiting and training postdoctoral students, graduate students and undergraduate students from the learning sciences, computer sciences and bioengineering on the latest educational theories and practical applications to the field of bioengineering education. The center also strives to bring training opportunities to present bioengineering faculty. K-12 educators and students benefit from the efforts of VaNTH to raise awareness of the field of bioengineering and to provide opportunities for students and instructors to use VaNTH teaching materials.

The goals of the education program are:

Goal 1: Attract and retain highly qualified postdoctoral students, graduate students and undergraduate students to participate in the education activities of VaNTH.

Goal 2: Develop and disseminate modules, workshop materials, seminars and courses that emphasize training in basic elements of education for bioengineering graduate students and university educators. A major requirement of bioengineering professors is that they teach. Little or no preparation is provided in this area, and yet there is an extensive educational research knowledge base that can inform their teaching. The ultimate goal is to provide current bioengineering professors, graduate students, and postdoctoral students with knowledge of current research-based effective practices in education so that they may be better teachers in their field.

Goal 3: Provide training in basic HPL[1] Philosophy and Methodology to those who will be developing and delivering VaNTH HPL educational materials. This is an integrated effort between the Education Program and the LS[2], LT[3] and AE[4] thrusts. Recipients of this training include professors, post-doctoral students, graduate teaching assistants, VaNTH graduate students, REU[5] students, RET K-12[6] teachers, and students involved in developing modules.

Goal 4: Ensure that each VaNTH student is properly supervised, has adequate industrial and professional exposure, and is an integral member of an interdisciplinary research team.

Goal 5: Maintain a database of ERC students and their related activities.

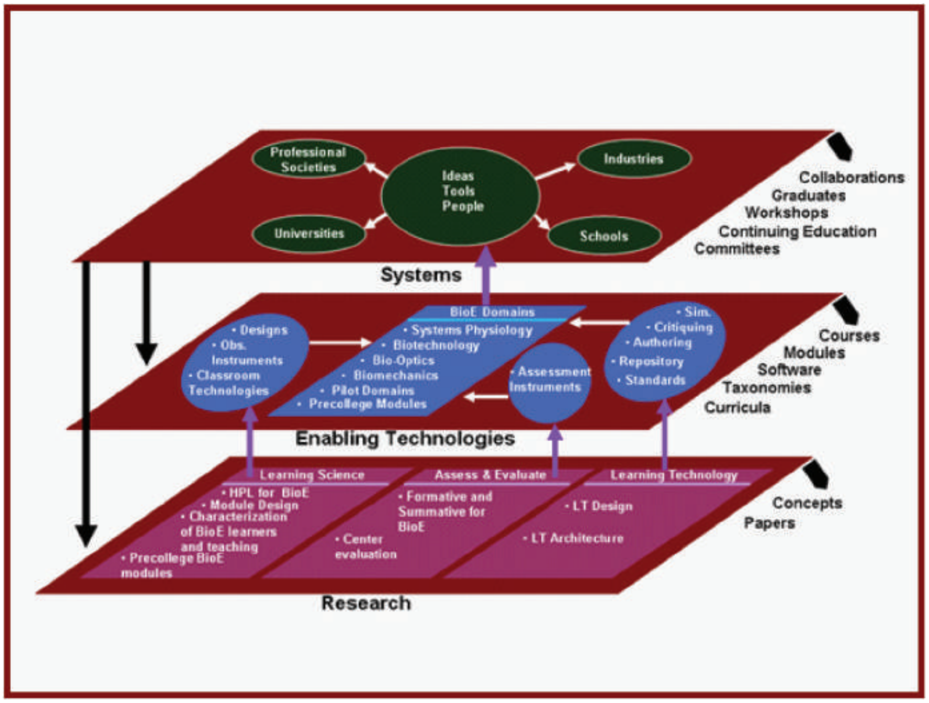
Goal 6: Inform teachers, learners and the general public about the learning science principles embodied in "How People Learn" and help teachers apply HPL principles in their domains.

Goal 7: Use VaNTH resources to raise awareness of biomedical engineering in general, particularly in K-12 students, and to increase the quality of the students going into bio/medical engineering."

Figure 4 depicts Harris's illustration of the various relations existing under the umbrella of VaNTH ERC (Harris, 2001).

The footnoted acronyms mentioned under Goal 3 are worthwhile to be clarified to the reader. According to VaNTH-ERC, Learning Sciences (LS) constitute a major project area involved in developing means to better understand "*bioengineering students as learners*" and "*methods that help them learn*" so as to identify what could be the effects of "*technology and curriculum change*" on the students and to attain optimum teaching standards in all constituting areas of bioengineering. Learning Technology (LT) is another area whereby VaNTH-ERC plans to research means of inventing and extending learning technologies specific to bioengineering education, as well as putting into practice and assessing these technologies within the classroom settings and throughout all VaNTH-ERC's venues. As inferred from the aforementioned points, VaNTH-ERC uses the strategy of Assess and Evaluate (AE) as a major component of research emphasis and enabling technologies (Anonymous, 2000). The Research Experiences for Undergraduates (REU) constitute competitive summer research programs under the sponsorship of the National Science Foundation (NSF, Arlington, Virginia, USA) and are hosted in various universities within the United States for undergraduate students enrolled in areas pertaining to science, engineering, or mathematics. Finally, RET K-12 refers to Research Experience for Teachers, whereby high school science teachers conduct supervised independent research projects at a host institution of higher learning during a summer interim.

Figure 4. A comprehensive flow diagram depicting the various relations underneath the umbrella of VaNTH Engineering Research Center. Adapted from Harris, 2001.



1.5.2. The Whitaker Foundation – International Summit Meetings of Biomedical Engineering Education

The two summit meetings that the Whitaker Foundation held in 2000 and 2005, respectively, had resulted in what is recognized as the *Whitaker Curriculum Philosophy* (Anonymous, 2006b) pertaining to research and education in biomedical engineering. This philosophy fosters the following criteria:

1. A thorough understanding of the life sciences, with the life sciences a critical component of the curriculum.
2. Mastery of advanced engineering tools and approaches.
3. Familiarity with the unique problems of making and interpreting quantitative measurements in living systems.
4. The ability to use modeling techniques as a tool for integrating knowledge.
5. The ability to formulate and solve problems with medical relevance, including the design of devices, systems, and processes to improve human health.

The Whitaker Foundation summit meetings on professional education also adopted another complementary philosophy to be used in designing and modifying bioengineering/biomedical engineering curricula, and named it the *ABET Curriculum Philosophy* (Anonymous, 2006b), which is defined in Section 1.5.3.

1.5.3. The Accreditation Board for Engineering and Technology – EC2000

The Accreditation Board for Engineering and Technology, Inc., ABET, Baltimore, MD, USA has disseminated a set of standards to be met by educational programs in bioengineering/biomedical engineering in order to be accredited by this agency (Katona, 2002; Enderle *et al.*, 2003; Anonymous, 2006b; Anonymous, 2007a).

In order to receive accreditation, undergraduate programs in bioengineering and biomedical engineering must demonstrate that their graduates reach the following outcomes (Anonymous, 2006b; Anonymous, 2007a):

a. “an ability to apply knowledge of mathematics, science, and engineering;
b. an ability to design and conduct experiments, as well as to analyze and interpret data;
c. an ability to design a system, component, or process to meet desired needs;
d. an ability to function on multi-disciplinary teams;
e. an ability to identify, formulate, and solve engineering problems;
f. an understanding of professional and ethical responsibility;
g. an ability to communicate effectively;
h. the broad education necessary to understand the impact of engineering solutions in a global and societal context;
i. a recognition of the need for, and an ability to engage in, life-long learning;
j. a knowledge of contemporary issues;
k. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice; and, specific to bioengineering and biomedical engineering,
l. an understanding of biology and physiology, and the capability to apply advanced mathematics (including differential equations and statistics), science, and engineering to solve the problems at the interface of engineering and biology;
m. the ability to make measurements on and interpret data from living systems, addressing the problems associated with the interaction between living and non-living materials and systems.”

“Furthermore, the criteria indicate that ‘Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social and political.’” (Anonymous, 2006b).

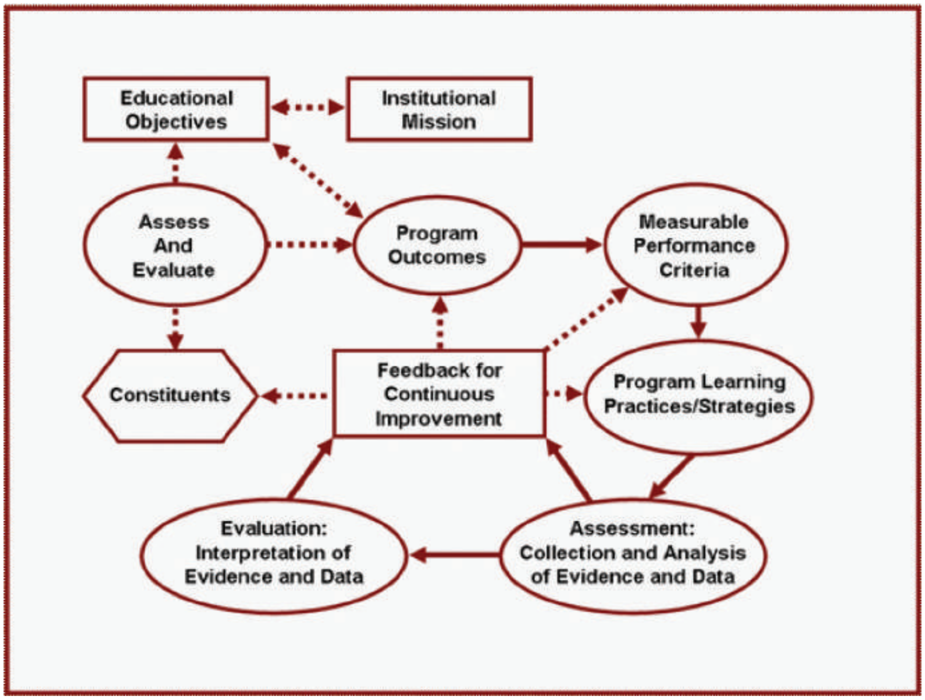
It is worthy to note that outcomes a-k constitute ‘*Criterion 3 - Program Outcomes*’ of the EC2000 of ABET, described earlier in this chapter, whereas outcomes l-m constitute the ‘*Program Criteria for Bioengineering and Biomedical Engineering and Similarly Named Engineering Programs’*; which begins with the statement “The structure of the curriculum must provide both breadth and depth across the range of engineering topics implied by the title of the program” (Anonymous, 2007a).

To ensure a successful program visit, Enderle *et al.*, and based on an ABET training diagram, depicted their expert view of the process of continuous improvement that a biomedical engineering undergraduate program should undergo (Enderle *et al.*, 2003). The recommended assessment procedure is presented in Figure 5.

1.6. CAREER DEVELOPMENT

There is no doubt that the field of Bioengineering/Biomedical Engineering is ever evolving due to the reciprocal leapfrog between science and technology; accordingly, emerging areas are frequently introduced to augment the well-established subdivisions of this field. This reality has been previously envisioned by Harris *et al.*, who drew attention to the fact that there have been different ‘*paradigm shifts*’ in biology, medicine, and engineering between 1975 and 1995 (Harris *et*

Figure 5. Enderle et al.'s view of an assessment procedure to be pursued by a biomedical engineering undergraduate program to ensure a successful ABET visit. Adapted from Enderle et al., 2003.



al., 2002). The authors added that "Keeping pace with this field requires a new kind of student - a student who can rapidly adapt to new information and recognize the potential for applying this knowledge to existing problems of human health and biology" (Harris *et al.*, 2002). Despite the fact that the literature contains considerable recommendations pertaining to career development in Bioengineering/Biomedical Engineering (Harris *et al.*, 2002; Harmon, 1975; Katona, 2002; Jacobs, 1975; Mylrea and Sivertson, 1975; Schwartz and Long, 1975; Viik and Malmivuo, 1999; Gatchell *et al*., 2004), these recommendations are non-explicit, fragmented, and frequently have to be deduced. Moreover, basic career guidance in this field has been mostly gleaned from professional societies and organizations. Hence, it would be laborious for a prospective university student in bioengineering/biomedical engineering to conduct an intensive literature survey so as to assemble career guidelines that are all-inclusive. Accordingly, a comprehensive list of career guidelines has been compiled by Abu-Faraj (2008) and assembled into a roadmap to steer the prospective student towards a smoothly planned and designed career path in this vital field. These guidelines stem from the author's expertise, in-depth knowledge of the literature, and field of experience as a founding chair of a contemporary regional premier comprehensive undergraduate biomedical engineering curriculum that was launched in Lebanon in 2002 (Abu-Faraj, 2005). Additional information pertaining to career planning and designing in Bioengineering/Biomedical Engineering is accessible on-line from the website of the Biomedical Engineering Society, Landover, MD, USA (Anonymous, 1996) as well as that of the IEEE Engineering in Medicine and Biology Society, Piscataway, NJ, USA (Anonymous, 2003). Abu-Faraj believes that "career development in Bioengineering/Biomedical Engineering starts with a passion nurtured with a decisive aptitude, augmented with a keen vision, strategic planning, and careful design that are fulfilled with an enrollment in a solid curriculum, thereof securing vocational success and prosperity" (Abu-Faraj, 2008).

As such, the ensuing text aims to present a set of strategies and recommendations to be pursued by individuals seeking to plan and design careers in bioengineering/biomedical engineering. The intent is to address the international student considering bioengineering/biomedical engineering as a career, with an inherent emphasis on the student within developing and transitional countries where career guidance is scarce. Concurrently, academic institutions of higher education, ministries of higher education, and other governmental agencies, mainly within such countries, who intend to launch or reform bioengineering/biomedical engineering curricula are also targeted.

Abu-Faraj stated that "The roadmap toward a successful career in Bioengineering/Biomedical Engineering is normally an intricate process interwoven with inherent challenges" (Abu-Faraj, 2008). He expounded by addressing individuals seeking a career in this field, or in any of its subdivisions, through a set of 20+ recommendations intended to smooth the path. These recommendations are presented herein (Abu-Faraj, 2008):

1. "Have a passion for the field and an objective assessment of your capabilities.
2. Determine your goals and objectives, taking into consideration the advancements of the field in the next decades.
3. Develop a comprehensive understanding of the field and its key divisions.
4. Work to attain a professional aptitude built upon concrete pillars: integrity, authenticity, seriousness, commitment, punctuality, reliability, responsibility, professionalism, and motivation.
5. Enroll in a competitive undergraduate program in Bioengineering/Biomedical Engineering; whether a track option emphasizing one or more related subdivisions or a comprehensive program. The difference between a track option and a comprehensive program is addressed hereinafter.
6. Be careful when choosing a track option curriculum for it to be commensurate with job opportunities within the region you plan to settle in. Certain regions might be void of opportunities in a selected track.
7. Choose a program that integrates courses in biomedical sciences within the bioengineering/biomedical engineering curriculum (Katona, 2002; Jacobs, 1975; Schwartz and Long, 1975; Anonymous, 2006b). Biomedical sciences courses include, but are not limited to, cellular and molecular biology, general and organic chemistry, biochemistry, and anatomy and physiology.
8. Choose a curriculum that deploys the bioengineering/biomedical engineering program at both levels of education: theoretical and applied (Harris *et al.*, 2002). Applied education encompasses design courses, research and development, laboratory courses, knowledge of manufacturing issues, and utilization of simulation and modeling techniques (Anonymous, 2006b; Anonymous, 2007a).
9. Develop an understanding of professional and ethical responsibilities (Anonymous, 2006b; Anonymous, 2007a).
10. Strengthen your oral and written communication skills in more than one language (Anonymous, 2006b; Anonymous, 2007a); especially in English since it is becoming the dominant international language of communication (Viik and Malmivuo, 1999).
11. Challenge your critical thinking abilities and work on augmenting your analytic and problem solving skills (Anonymous, 2006b; Anonymous, 2007a).
12. Take one or more course(s) in management of physical, human, and financial resources. These are vital for enhancing the ability to

deal effectively with vocational daily life challenges.

13. Nurture your abilities to work with teams and making group decisions. Be as well prepared to function on multi-disciplinary teams (Viik and Malmivuo, 1999; Anonymous, 2006b; Anonymous, 2007a). Harmon speculated that "In all likelihood most biomedical engineers of the future will be modified interdisciplinary hybrids" (Harmon, 1975).
14. Perform practical bioengineering/biomedical engineering training, cooperative educational training, or industrial internship, in an area pertaining to your choice of specialization (Schwartz and Long, 1975; King, 1999; Fries, 2003; Waples and Ropella, 2003). Many academic programs mandate this training as a partial requirement towards the fulfillment of the undergraduate degree.
15. Attend relevant summer workshops and wherever possible do volunteering work in pertinent areas of healthcare.
16. Choose the right technical elective courses, while pursuing your undergraduate degree, as a prelude to identify the most preferable divisions of interest to specialize in should you decide later to enroll in graduate school.
17. Forecast the labor market needs and expectations. Be equally aware of opportunities and threats.
18. Revise and validate your original academic and/or career plan and design by seeking the advice of vocational counselors and/or experts in the field, or even by cross-referencing it with published information.
19. Subscribe to one or more bioengineering/biomedical engineering society or organization. Such endeavor would offer immeasurable opportunities to keep track with advancements and breakthroughs in the said fields. In addition, it would provide an opportunity to have a national, regional, and global exposure.
20. Have a strong and well organized resume or curriculum vitae at hand. A good source would be the one used by the European Commission on the following website[‡]: www.ec.europa.eu/comm/education/index_en.html. Another recommended source for preparing a resume or curriculum vitae is found online under the title 'Research and Training Opportunities at the National Institutes of Health - US Department of Health and Human Services'[‡]: https://www.training.nih.gov/careers/careercenter/cv.html
21. Work towards obtaining a license as a professional engineer (PE or PEng) soon after your graduation, because several years of experience are often mandatory before receiving this license. There are four main reasons for becoming a licensed PE or PEng: i) it is a legal necessity in many countries; ii) it improves employment security; iii) it offers better opportunities for career advancement; and iv) it provides personal satisfaction (Steadman, Year unknown). It is worth noting that the requirements to accomplish such a process differ from one country or region to another. Should your country or region not provide professional licensure in Bioengineering/Biomedical Engineering, seek a license in a more generic engineering area, such as Electrical Engineering, Mechanical Engineering, or even General Engineering.
22. Be always prepared for a job interview.
23. Engage in life-long learning (Anonymous, 2006b; Anonymous, 2007a; Nagel *et al.*, 2007).

24. Perform a self check periodically on the veracity of your footsteps while pursuing your career path."

1.7. ACADEMIC CURRICULA IN BIOENGINEERING/ BIOMEDICAL ENGINEERING

Development in bioengineering/biomedical engineering curricula has proven to be an evolutionary process. In this context, Katona utilized a '*bridge model*' linking Engineering and Life Sciences so as to display the '*changing philosophies of biomedical engineering education*' over three major eras: i) circa 1960-1980, the bridge was unidirectional and basically slender and frail - "engineering techniques were being applied to solve problems in the life sciences and medicine"; ii) circa 1980-late 1990s, "the biological revolution mandated that students' knowledge of the life sciences be broadened", thus fortifying the bridge and transforming it into a bidirectional one; and iii) late 1990s-20??, bioengineering/biomedical engineering education fosters an integrative approach between the two fields with sufficient '*breadth and depth*' that annuls the need for a bridge (Katona, 2002).

Though no consensus about a single curriculum in bioengineering/biomedical engineering has been reached, and most likely there would not be any in the near future, the orientation of curricula in the field in an optimal direction have long been pursued by authorities.

Programs in Bioengineering/Biomedical Engineering are currently divided into those which i) offer a comprehensive curriculum in the field with emphasis on the biomedical sciences, and those which ii) specialize in a specific track option pertaining to one or more of the key divisions within this field, excluding other fundamental subdivisions. Although the latter is very attractive to industry, in the sense that it often culminates in expertise within a unilateral subdivision or branch of Bioengineering/Biomedical Engineering, yet there exists a debate on whether such a track could become an impediment to flexibility in general as well as mastering the basics of Bioengineering/Biomedical Engineering; particularly in such an ever evolving field. Harmon recommended that "Intermediate and high-level educational tracks must be made extremely flexible in order to accommodate the many multi-discipline subspecialties" within this field (Harmon, 1975). This vital issue ought to be taken as a stepping stone when designing new curricula in Bioengineering/ Biomedical Engineering, particularly in developing and transitional countries.

Irrespective of the nature of the programs, academic curricula in Bioengineering/Biomedical Engineering should well-equip prospective graduates with adequate theoretical and applied expertise to confront the proliferating intricate competitive reality that faces the young generations subsequent to their graduation. Hence, the main thrust of these curricula should be directed towards establishing a '*common knowledge base*' for these bioengineers/biomedical engineers, regardless of what division of the field they may delve into.

At this point, the reader could benefit from consulting the paper '*Roles for Learning Sciences and Learning Technologies in Biomedical Engineering Education: A Review of Recent Advances*'; especially, the section discussing the four barriers to be overcome when addressing curriculum issues in bioengineering/biomedical engineering education, namely: i) "*The Biology-Engineering Barrier*"; ii) "*The Learning Science-Engineering Education Barrier*"; iii) "*Technology-Education Barrier*"; and iv) "*The Academe-Industry/Practice Barrier*" (Harris *et al*., 2002).

As for academic institutions of higher learning that are aiming at subscribing to the development of new curricula in Bioengineering/Biomedical Engineering, chiefly in the above-mentioned countries where the ministries of higher education and other governmental agencies are possible decision-making entities, Abu-Faraj delineated 10 recommendations, though not novel, to be seriously contemplated (Abu-Faraj, 2008):

1. "To thoroughly adhere to the VaNTH-ERC recommendations pertaining to the five broad categories described earlier in Section 1.4 Historical Background and Literature Overview (Anonymous, 1999; Gatchell, 2004).
2. To follow the Whitaker and ABET Curriculum Philosophies set by the Whitaker Foundation 2005 Summit Meeting (Anonymous, 2006b; Anonymous, 2007a).
3. To use outcome measures aimed at assessing the success of the established curriculum in order to provide guidance to the curriculum planner (Harris *et al.*, 2002; Viik and Malmivuo, 1999).
4. To collaborate with leading academic programs in Bioengineering/Biomedical Engineering worldwide, particularly within the European Community and the United States.
5. To integrate biomedical sciences courses into the bioengineering/biomedical engineering curricula (Katona, 2002).
6. To introduce a practical bioengineering/biomedical engineering training, cooperative education, or industrial internship program into the curriculum as a partial requirement towards the fulfillment of the undergraduate degree (Schwartz and Long, 1975; King, 1999; Fries, 2003; Waples and Ropella, 2003).
7. To select specialized/qualified faculty with expertise and extensive knowledge in more than one division (multidisciplinary) of Bioengineering/Biomedical Engineering (Anonymous, 1999).
8. To launch the bioengineering/biomedical engineering program at both levels of education: *theoretical* and *applied*; taking into consideration that learning technology, linked with new ideas from learning science, can result in increased effectiveness in student's learning (Harris *et al.*, 2002).
9. To prepare competitive course syllabi that comply with the VaNTH-ERC and ABET standards. As well as, to carefully and appropriately select course textbooks and references (Anonymous, 1999; Gatchell, 2004; Anonymous, 2006b; Anonymous, 2007a).
10. To integrate simulation and modeling tools, multi-media teaching aids, and teaching resources into the various course syllabi within the bioengineering/biomedical engineering program. Moreover, Harris *et al.* recommended the intensive use of "*case-based, problem-based, and project-based learning*" while teaching biomedical engineering (Harris *et al.*, 2002)."

In 2002, and in an effort to remedy the deficiency in the role of bioengineering/biomedical engineering education within the Middle East and Northern African (MEDA) region, as well as to respond to the local and regional socio-economic requirements, the American University of Science & Technology, AUST, Beirut, Lebanon, developed a world-class competitive and comprehensive undergraduate program in Biomedical Engineering (Abu-Faraj, 2005). This program, considered one of the regional premier curricula in Bioengineering/Biomedical Engineering, was carefully designed in compliance with the VaNTH-ERC recommendations and the Whitaker and ABET Curriculum Philosophies, as well as with the other recommendations highlighted above (Abu-Faraj, 2005; Abu-Faraj, 2006). Of particular interest is the umbrella category '*ii) steps to creating a curriculum*' introduced by VaNTH-ERC (addressed in Section 1.4), which recommended the following: a) "Define the type(s) of biomedical engineer that the program will produce and the career paths the program will prepare them for"; and b) "Seek multiple perspectives and involve multiple constituencies in the curricular design process. Consider the following as sources of input on curriculum: taxonomy, faculty expertise, students, industry needs, existing programs, and ABET guidelines and outcomes" (Anonymous, 1999).

Today, this program has become a prototype of a modern and a well-developed curriculum in the field; and is now recognized as '*The AUST Undergraduate BME Curriculum Model*'. It is a post-freshman, hybrid, four-year program that leads to a Bachelor of Science degree in Computer and Communications Engineering (CCE) with specialization in Biomedical Engineering (BME) & Biomedical Sciences (BMS). As part of its evolutionary aspiration, it is worth to note that this program is undergoing a full transition to become an independent Biomedical Engineering program without compromising its content. This process has reached an advanced phase with the Lebanese Ministry of Higher Education. The AUST undergraduate biomedical engineering curriculum model is presented in Table 3.

Five generations of biomedical engineers have graduated from this program between 2006 and 2010. Several of these students have been accepted to pursue their graduate studies in the said field, at the M.S. and Ph.D. levels, at renowned academic institutions worldwide, such as: Cornell University, Ithaca, NY, USA; New Jersey Institute of Technology, NJIT, Newark, NJ, USA; Politecnico University di Milano, POLIMI, Milan, Italy; Swiss Federal Institute of Technology – Zurich, ETH, Zurich, Switzerland; l'École Polytechnique de Montréal, Montréal, Québec, Canada; l'Université de Technologie Compiègne, UTC, Compiègne Cedex, France; and the Fach Hochschule Lübeck - University of Applied Sciences, Lübeck, Germany. The other graduates, along with those who have earned their graduate degrees, have been successfully employed in bioengineering/biomedical engineering firms in Lebanon and abroad. Interestingly, there is a rising demand for AUST biomedical engineering graduates within the local market that exceeds the supply; a factor that does not only reflect the quality of their education, but also adds value to their remuneration.

The compatibility of the AUST undergraduate BME curriculum model is made apparent when it is contrasted with a generic curriculum of Vanderbilt University - a founding member of the VaNTH-ERC and an ABET-EAC accredited program since 1992. Table 4 illustrates the undergraduate biomedical engineering curriculum at Vanderbilt University.

1.8. PROJECT ALEXANDER THE GREAT: A STUDY ON THE WORLD PROMULGATION OF BIOENGINEERING/BIOMEDICAL ENGINEERING EDUCATION

Despite the notable advancements in Bioengineering/Biomedical Engineering that have been discussed in the previous sections of this chapter, there are still numerous shortcomings that await serious intervention. These shortcomings are basically related to the deficiency in coordinated interaction among an intricate body of key-players within this field, involving students, universities, hospitals, industries, professional societies and organizations, and governmental agencies and ministries; and which have resulted in "*the right hand not knowing what the left hand is doing*" syndrome among the constituting entities. Therefore, in order to enhance and solidify the global promulgation of Bioengineering/Biomedical Engineering as a field, this deficiency awaits to be appropriately rectified. There is no doubt that awareness pertaining to the aforementioned shortcomings exists within the bioengineering/biomedical engineering community; yet, the work done on alleviating these deficiencies has been restricted *per se* to organized student internships in industry and consortia of universities on a limited scale, and national and international conferences held by professional societies and organizations on a larger scale.

Table 3. The AUST Undergraduate BME Curriculum Model

BS in Computer and Communications Engineering		
Specialization in Biomedical Engineering & Biomedical Sciences		
TOTAL REQUIRED CREDITS FOR GRADUATION		
BEGINNING FROM THE SOPHOMORE YEAR (138 Credit Hours)		
GENERAL GRADUATION REQUIREMENTS (15 Credit Hours)		
CSI201	Introduction to Computing	3 cr.
ENG 201	Composition & Rhetoric I	3 cr.
ENG202	Composition & Rhetoric II	3 cr.
ENG205	English Communication Skills	3 cr.
HMS220	Arabic Communication Skills	3 cr.
FREE LIBERAL ARTS & NATURAL SCIENCES ELECTIVES (9 Credit Hours)		
HMS250	Methodology of Research	3 cr
SOS230	Introduction to Psychology	3 cr
SOS231	Social Psychology	3 cr
SOS235	Introduction to International Relations	3 cr
SOS240	Introduction to Sociology	3 cr
CHE201	General Chemistry (*Required for BMS specialization*)	3 cr
CHE210	Organic Chemistry (*Required for BMS specialization*)	3 cr
MATHEMATICS REQUIREMENTS (15 Credit Hours)		
MAT203	Calculus III	3 cr
MAT205	Linear Algebra	3 cr
MAT210	Probability & Statistics for Science	3 cr
MAT225	Differential Equations	3 cr
MAT315	Numerical Methods	3 cr
COMPUTER AND COMMUNICATIONS ENGINEERING MAJOR REQUIREMENTS (43 Credit Hours)		
CCE201	Circuit Analysis I.	3 cr
CCE201L	Circuit Analysis I Laboratory	1 cr.
CCE202	Circuit Analysis II	3 cr.
CCE202L	Circuit Analysis II Laboratory	1 cr.
CCE220	Digital Systems	3 cr.
CCE220L	Digital Systems Laboratory	1 cr.
CCE301	Electronics	3 cr.
CCE301L	Electronics Laboratory	1 cr.
CCE320	Computer Organization & Microprocessors	3 cr.
CCE320L	Computer Organization & Microprocessors Laboratory	1 cr.
CCE325	Computer Architecture	3 cr.
CCE401	Communication Systems	3 cr.

continued on following page

Table 3. Continued

CCE401L	Communication Systems Laboratory	1 cr.
CSI205	Computer Programming I (Functional Programming)	3 cr.
CSI205L	Computer Programming I Laboratory	1 cr.
CSI250	Computer Programming II (Object-Oriented Programming)	3 cr.
CSI250L	Computer Programming II Laboratory	1 cr.
CSI311	Java Programming	3 cr.
CSI311L	Java Programming Laboratory	1 cr.
CSI345	Computer Networks	3 cr.
CSI345L	Computer Networks Laboratory	1 cr.
BIOMEDICAL ENGINEERING SPECIALIZATION REQUIREMENTS (32 Credit Hours)		
BME200	Introduction to Biomedical Engineering	3 cr.
BME210	Introduction to Biomechanics I: Solid Mechanics	3 cr.
BME212	Introduction to Biomechanics II: Dynamics	3 cr.
BME317	Electrical Biophysics	3 cr.
BME330	Signals and Biosystems	3 cr.
BME400	Practical Biomedical Engineering Training	1 cr.
BME405	Biocontrol Systems	3 cr.
BME405L	Biocontrol Systems Laboratory	1 cr.
BME406	Biomedical Digital Signal Processing	3 cr.
BME481	Biomedical Instrumentation & Design	3 cr.
BME481L	Biomedical Instrumentation & Design Laboratory	1 cr.
BME490	Biomedical Engineering Ethics	1 cr.
BME497	Biomedical Engineering Project Proposal	1 cr.
BME499	Biomedical Engineering Senior Project	3 cr.
BIOMEDICAL ENGINEERING TECHNICAL ELECTIVES (6 Credit Hours)		
BME401B	The Human Body: Structure & Functions	3 cr.
BME410B	Biomedical Materials Considerations	3 cr.
BME450B	Biomedical Engineering Design	3 cr.
BME476B	Biofluid Mechanics	3 cr.
BME483B	Introduction to Magnetic Resonance Imaging	3 cr.
BME485B	Introduction to Optical Imaging	3 cr.
BME487B	Biomedical Robotics	3 cr.
BME489B	Artificial Intelligence in Medicine	3 cr.

Abu-Faraj (2010) recommended that "*the right hand not knowing what the left hand is doing*" syndrome could be effectively and strategically remedied by taking advantage of the world-wide-web to establish an interactive cyber-space network involving all key-players within the field and thus enhancing the communication among these entities. As such, in attempt to effectively

Table 4. The Undergraduate BME Curriculum at Vanderbilt University. Adopted from Vanderbilt University Undergraduate Catalog 2010-2011.

B.E. in Biomedical Engineering
MINIMUM REQUIRED CREDITS FOR GRADUATION
BEGINNING FROM THE FRESHMAN YEAR (127 Credit Hours)

CURRICULUM REQUIREMENTS:

1. Mathematics Requirements (15 Credit Hours).
2. Basic Science Requirements (24 Credit Hours): Chemistry, Physics, Biological Sciences, and a second approved biological sciences course with laboratory.
3. Introductory Engineering and Computing (6 Credit Hours): ES 140 and either CS 103 (preferred) or CS 101.
4. Electrical Engineering (7 Credit Hours): EECE 112, 213, 213L.
5. Biomedical Engineering (31 Credit Hours): BME 101, 103, 210, 251, 252, 255, 260, 271, 272, 273, 297.
6. Biomedical Engineering Electives (11 Credit Hours) from an approved departmental list.
7. Program Electives (9 Credit Hours): Science, Engineering, and Math courses from an approved departmental list.
8. Liberal Arts Core (18 Credit Hours) to be selected to fulfill the Liberal Arts Core requirements listed under Degree Programs in Engineering.
9. Open Electives (6 Credit Hours).

SPECIMEN CURRICULUM FOR ALL ENGINEERING DISCIPLINES:

The Freshman Year

Fall Semester

Chemistry 102a*	General Chemistry	3 cr.
Chemistry 104a	General Chemistry Laboratory	1 cr.
Mathematics 155a	Accelerated Single-Variable Calculus I	4 cr.
	Elective	3 cr.
Engineering Science 140	Introduction to Engineering	3 cr.
	Total	14 cr.

* Chemistry 102a students must also enroll in a recitation section of Chemistry 106a (zero credit hours).

Spring Semester

Chemistry 102b*	General Chemistry	3 cr.
and and		
Chemistry 104b*‡	General Chemistry Laboratory	1 cr.
or	or	
Materials Science150*‡	Materials Science I	4 cr.
Mathematics 155b	Accelerated Single-Variable Calculus II	4 cr.
Physics 116a	General Physics	3 cr.
Physics 118a	General Physics Laboratory	1 cr.
Engineering Science 101	Engineering Freshman Seminar (optional)	1 cr.
Computer Science 101 or 103	Programming and Problem Solving	3 cr.
	Total	15-16 cr.

‡ Chemical engineering and biomedical engineering majors must take Chemistry 102b and 104b.
* Chemistry 102b students must also enroll in a recitation section of Chemistry 106b (zero credit hours).

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augment the remedy of this syndrome, the author designed, introduced, and published an original study on the global spread of bioengineering/biomedical engineering education under the title '*Project Alexander the Great*' (Abu-Faraj, 2008a; Abu-Faraj, 2010).

Project Alexander the Great was launched in September 2007 by the Department of Biomedical Engineering at the American University of Science & Technology, AUST, Beirut, Lebanon. Its objectives are to: "identify, disseminate, and network, through the world-wide-web, all those institutions of higher learning that provide bioengineering/biomedical engineering education, with the potential of incorporating emerging programs" (Abu-Faraj, 2010).

The author believes that this endeavor will create the foundation and environment necessary for the above sought interactive communication among the various stakeholders within the field of Bioengineering/Biomedical Engineering. He further proclaims that the acquired information is essential, up-to-date, and could be beneficial not only to the following bioengineering/biomedical engineering target audience: students, faculty, research scientists, and practitioners,

Table 4. Continued

SPECIMEN CURRICULUM FOR BIOMEDICAL ENGINEERING:

	The Sophomore Year	
Fall Semester		
BioSci 110a	Introduction to Biological Sciences	4 cr.
BME 101	Introductory Biomechanics	3 cr.
Math 175	Multivariable Calculus	3 cr.
Phys 116b, 118b	General Physics with Laboratory	4 cr.
	Liberal Arts Core	3 cr.
	Total	17 cr.
Spring Semester		
BioSci 111a	Biological Sciences course*	4 cr.
BME 103	Biomedical Materials	3 cr.
Math 196	Differential Equations with Linear Algebra	4 cr.
EECE 112	Circuits I	3 cr.
	Liberal Arts Core	3 cr.
	Total	17 cr.

* A second biological sciences course with laboratory must be selected from the departmental list of approved courses.

	The Junior Year	
Fall Semester		
BME 210	Physiological Transport Phenomena	3 cr.
BME 251	Systems Physiology	3 cr.
EECE 213, 213L	Circuits II	4 cr.
	Biomedical Engineering or program elective***	3 cr.
	Open Elective	3 cr.
	Total	16 cr.

	The Senior Year	
Fall Semester		
BME 255W	Biomedical Engineering Laboratory	3 cr.
BME 272	Design of Biomedical Engineering Systems I	2 cr.
BME 297	Senior Engineering Design Seminar	1 cr.
	Biomedical Engineering or program elective***	7 cr.
	Liberal Arts Core	3 cr.
	Total	16 cr.
Spring Semester		
BME 273	Design of Biomedical Engineering Systems II	3 cr.
	Biomedical Engineering or program elective***	6 cr.
	Liberal Arts Core	3 cr.
	Open Elective	3 cr.
	Total	15 cr.

** BME 271 may also be taken in the fall of the senior year.
*** BME and program electives must be selected from a list of approved courses available in the department office.

but to other closely-related entities, including industry, accreditation agencies, professional societies, academic institutions of higher education, ministries of higher education, and other governmental agencies.

The initial step of Project Alexander the Great was to establish a database of the academic institutions of higher learning offering bioengineering/biomedical engineering education. Consequently, a survey was conducted on all 10453 universities recognized by the International Association of Universities, UNESCO, Paris, France (Anonymous, 2007b), spread among the 193 member states of the United Nations, New York, NY, USA, within the six continents. Table 5 delineates the classifications comprising the database that was created thereof. This table, according to the author, presents a 0.06125% discrepancy in the sum total of the continent population from that of the total population, reflecting the population of small islands and Western Sahara which was not accounted for.

Using Google's search engine, Google Inc., Mountain View, CA, USA, a world-wide-web (www) search was initiated by continent. Once an institution was identified to have a bioengineer-

Table 5. The clusters and properties of the study database. (Population Data Source: World Population Prospects - The 2008 Revision, Department of Economic and Social Affairs, United Nations, New York, NY, USA, 2009). Source: Abu-Faraj, 2010 - Courtesy of Intech Open Access Publisher, Vienna, Austria, EU.

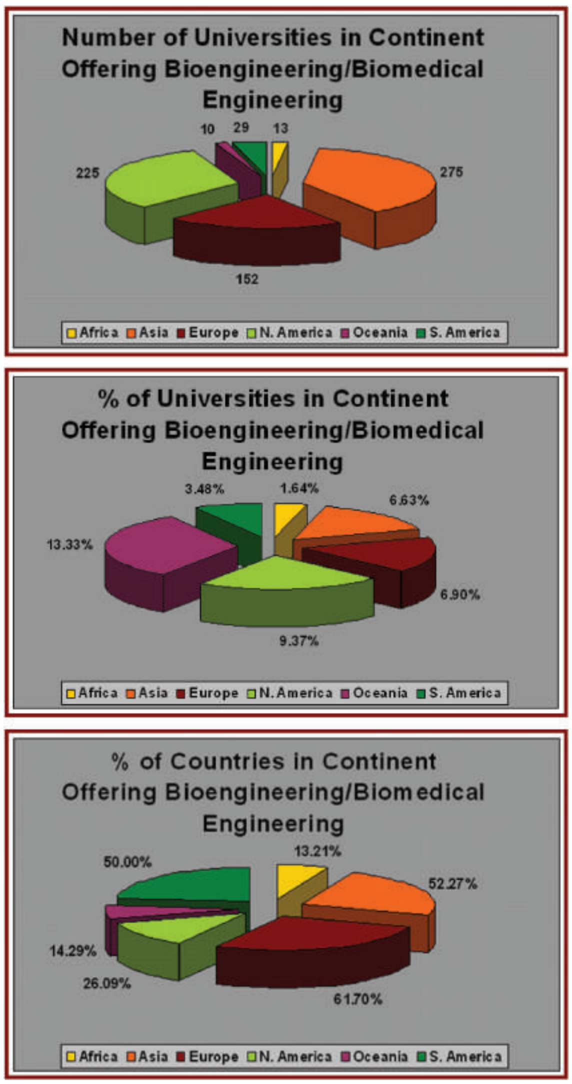
CLUSTERS	**PROPERTIES**		
Continent	**Countries**	**Population**	**Academic Institutions**
Africa	53	1007430000	793
Asia	44	4244615000	4147
Europe	47	610708000	2204
N. America	23	539611000	2401
Oceania	14	33946000	75
S. America	12	388868000	833
TOTAL	**193**	**6829361000**	**10453**

ing/biomedical engineering program, the concerned department's name, address, Uniform Resource Locator (URL), year established, and director's name and coordinates were gathered. Due to the magnitude of the work and the perseverance needed to acquire the desired data, a methodical search procedure was deemed essential and, hence, was set and implemented. This

Table 6. The distribution of bioengineering/biomedical engineering education in the six continents. (Population Data Source: World Population Prospects - The 2008 Revision, Department of Economic and Social Affairs, United Nations, New York, NY, USA, 2009). Source: Abu-Faraj, 2010 - Courtesy of Intech Open Access Publisher, Vienna, Austria, EU.

World Population						6829361000
World Countries						193
Total World Universities						10453
CONTINENT DATA	**AFRICA**	**ASIA**	**EUROPE**	**NORTH AMERICA**	**OCEANIA**	**SOUTH AMERICA**
Continent Population	1007430000	4244615000	610708000	539611000	33946000	388868000
Total Continent Countries	53	44	47	23	14	12
Continent Countries w/ Universities	48	44	46	17	7	12
Continent Population Offered Higher Education	1006566000	4244615000	610708000	539611000	33946000	388868000
Continent Population Not Offered Higher Education	864000	0	0	0	0	0
Number of Universities in Continent	793	4147	2204	2401	75	833
Number of People Per Single Continent University	1269314	1023539	277091	224744	452613	466828
Number of Universities in Continent Offering Bioengineering/Biomedical Engineering	13	275	152	225	10	29
Number of Countries in Continent Offering Bioengineering/Biomedical Engineering	7	23	29	6	2	6
% of World Population in Continent	14.75%	62.15%	8.94%	7.90%	0.50%	5.69%
% of Continent Population Not Offered Higher Education	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%
% of World Countries in Continent	27.46%	22.80%	24.35%	11.92%	7.25%	6.22%
% of Total Continent Countries w/ Universities	90.57%	100.00%	97.87%	73.91%	50.00%	100.00%
% of Total World Universities in Continent	7.59%	39.67%	21.08%	22.97%	0.72%	7.97%
% of Universities in Continent Offering Bioengineering/ Biomedical Engineering	1.64%	6.63%	6.90%	9.37%	13.33%	3.48%
% of Countries in Continent Offering Bioengineering/ Biomedical Engineering	13.21%	52.27%	61.70%	26.09%	14.29%	50.00%

Figure 6. (Top) A pie chart showing the number of universities in each continent offering Bioengineering/Biomedical Engineering education. (Source: Abu-Faraj, 2010 - Courtesy of Intech Open Access Publisher, Vienna, Austria, EU). Middle) A pie chart showing the percentage of universities in each continent offering Bioengineering/Biomedical Engineering education. (Bottom) A pie chart showing the percentage of countries in each continent offering Bioengineering/Biomedical Engineering education.



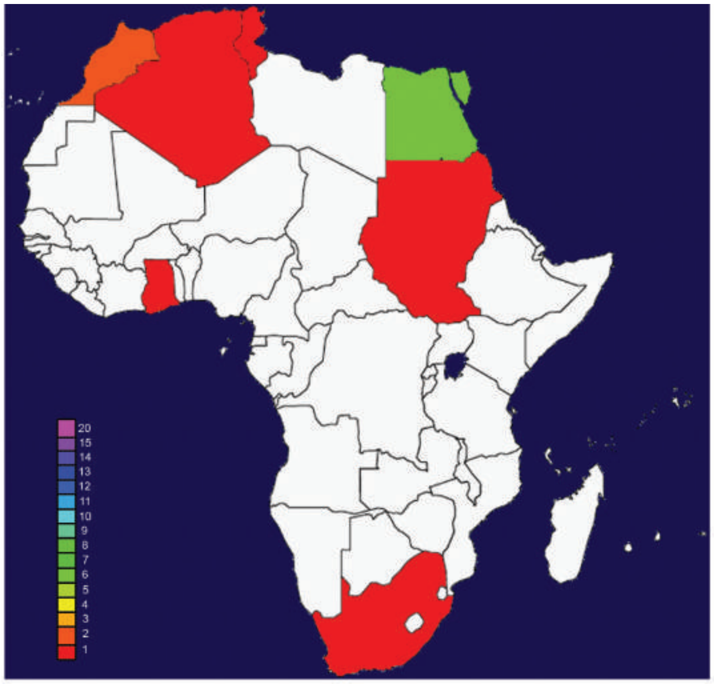
procedure consisted of two iterative processes explained herein.

The main iterative process was to employ the web. A cut-off limit of 15-20 minutes was set to identify whether or not an academic institution had a bioengineering/biomedical engineering program, after which the search proceeded to the next institution. The instantiation of a cut-off limit was found mandatory so as to evade any blockage that may unnecessarily hinder the process.

Instances of such hindrances included, but were not restricted to, language barriers, weak website design, and no or poor internet accessibility. Subsequent to the main iterative process, the *success rate* was computed as the ratio of the *number of successes* to the *total number of institutions*. A *success* was coined with the ability to connect, confirm (existence or no existence), and acquire information; while, *failure*, the compliment of *success*, meant the inability to connect or no information. The *success rates* were 70.74% for Africa, 66.19% for Asia, 82.67% for Europe, 94.13% for North America, 94.67% for Oceania, and 96.76% for South America.

In order to assert the study's findings, a second complementary iterative procedure, aiming at contacting the pertinent embassies/consulates/ministries of higher education, is in progress. This iteration is intended to boost the study's *success rates*. Moreover, the obtained *success rates* for South America, Oceania, North America, and Europe strongly support the methodology implemented in Project Alexander the Great. As for the *success rates* pertaining to Africa and Asia, which are considered satisfactory, there are several possible reasons behind these values, the main reasons being language barriers – particularly in Asia because of the vast spectrum of differing languages, e.g., Russian, Farsi, Chinese, Japanese, Korean, etc.; inexistence of a website; weak/non-interactive website design; no or poor internet accessibility; lack/inadequate published information; contaminated websites, among others.

Figure 7. The mapping of Bioengineering/Biomedical Engineering education in Africa. Note that the white shade indicates zero programs in a country. Source: Abu-Faraj, 2010 - Courtesy of Intech Open Access Publisher, Vienna, Austria, EU.



Algeria	1	Ghana	1	South Africa	1	Tunisia	1
Egypt	6	Morroco	2	Sudan	1		

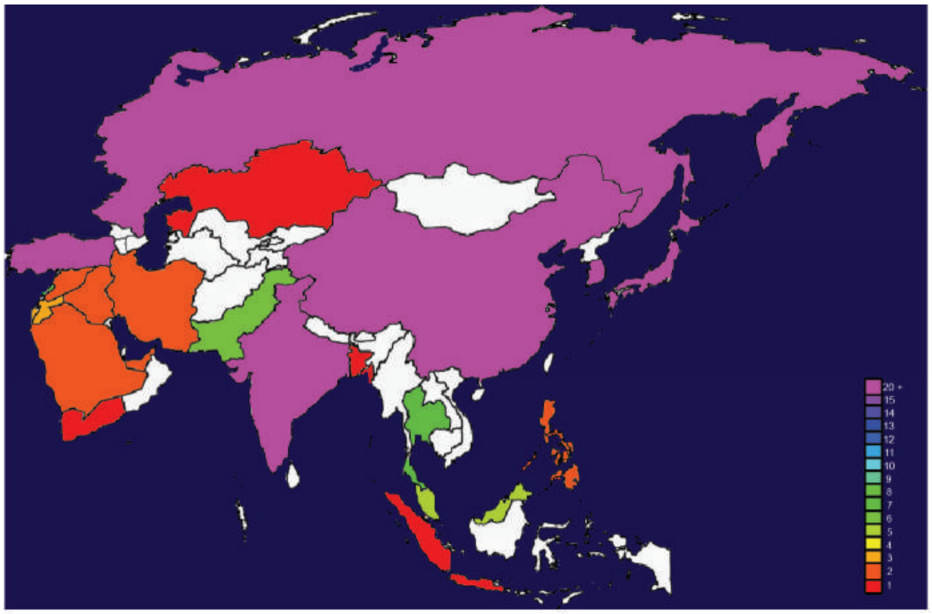
Because of the obtained high rates of success, the possibility of having a bioengineering/biomedical engineering program erroneously marked as '*failure*' is not perceived as problematic. Such an inadvertent error could be rectified by having the concerned academic institution fill out and submit an *e*-form, which is provided on the project's website, whose URL is www.projectalexanderthegreat.com. In any case, encountered *failures* are expected to diminish with time as long as the sustainability of Project Alexander the Great is maintained.

Table 6 depicts the statistical results of the distribution of bioengineering/biomedical engineering education within the six continents.

To simplify the navigation through this table, which depicts 19 items of data pertaining to the six continents, the data could be compartmentalized into five categories: i) generic data about the world population, world countries, and recognized world universities; ii) basic demographic, geographic, and academic data by continent; iii) Project Alexander the Great survey data pertaining to universities and countries offering bioengineering/biomedical engineering education by continent; iv) statistical distributions pertaining to demographic, geographic, and academic data by continent; and v) Project Alexander the Great statistical distributions pertaining to universities and countries offering bioengineering/biomedical engineering education by continent.

According to Table 6, there is good evidence that bioengineering/biomedical engineering educations has globally proliferated; this fact is illustrated in Figure 6 (Top and Middle), which shows the number and percentage of universities in each continent offering curricula in this field. Figure 6 (Bottom) also highlights the fact that the

Figure 8. The mapping of Bioengineering/Biomedical Engineering education in Asia. Source: Abu-Faraj, 2010 - Courtesy of Intech Open Access Publisher, Vienna, Austria, EU.



Bangladesh	1	Israel	3	Malaysia	5	Syria	2
China	90	Japan	32	Pakistan	6	Thailand	7
India	31	Jordan	3	Philippines	2	Turkey	21
Indonesia	1	Kazakhstan	1	Russian Federation	24	United Arab Emirates	2
Iran	2	Korea	27	Saudi Arabia	2	Yemen	1
Iraq	2	Lebanon	8	Singapore	2		

aforementioned numbers are clustered within each continent as reflected in the percent of countries in continent offering bioengineering/biomedical engineering education: 13.21% for Africa, 52.27% for Asia, 61.70% for Europe, 26.09% for North America, 14.29% for Oceania, and 50.0% for South America.

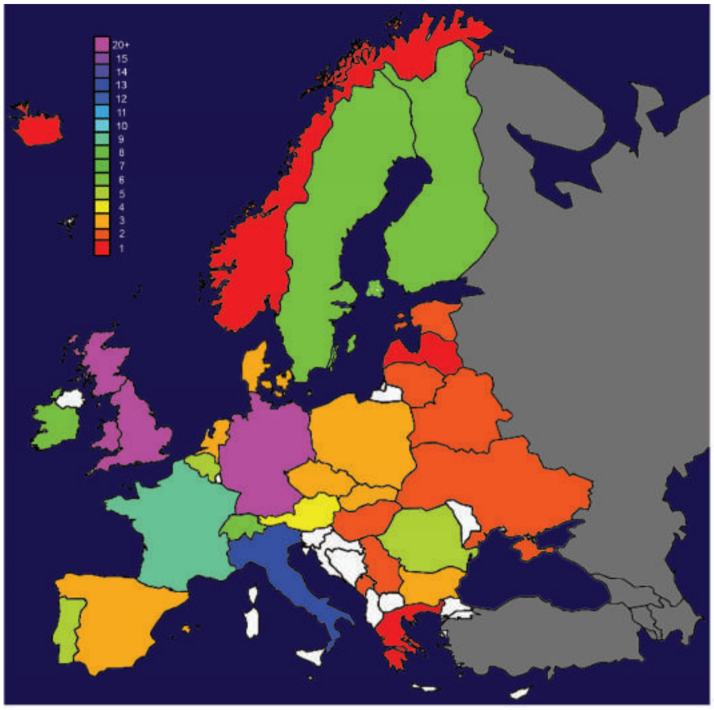
Furthermore, an appraisal of the evolution and proliferation of bioengineering/biomedical engineering as a field of study, in a chronological order since its inception in ca. 1959, concurrently with the current global boom in technology that is outreaching what were once considered as remote areas, indicate that the next few decades will probably witness a wider diffusion of bioengineering/biomedical engineering education into new countries within each continent.

Such diffusion is thought to become more viable if enrichment and solidification are realized within the coordinated interaction among the key players in the field of bioengineering/biomedical engineering, namely students, universities, hospitals, industries, professional societies and organizations, and governmental agencies and ministries.

Figure 7 through 12 illustrate the mapping of the current state of bioengineering/biomedical engineering education within the six continents. These figures are complemented with a basic analysis pertaining to the academic distribution of the field of bioengineering/biomedical engineering within each continent.

To better understand the illustrated distribution within each continent, Abu-Faraj formulated a new metric which first divided the number of population in a continent by the number of bioengineering/biomedical engineering programs offered within the same continent; then, the small-

Figure 9. The mapping of Bioengineering/Biomedical Engineering education in Europe. Source: Abu-Faraj, 2010 - Courtesy of Intech Open Access Publisher, Vienna, Austria, EU.



Austria	4	France	9	Lithuania	2	Spain	3
Belarus	2	Germany	23	Netherlands	3	Sweden	6
Belgium	5	Greece	2	Norway	1	Switzerland	6
Bulgaria	3	Hungary	2	Poland	3	Ukraine	2
Czech Republic	3	Iceland	1	Portugal	5	United Kingdom	26
Denmark	3	Ireland	6	Romania	5		
Estonia	2	Italy	13	Serbia	2		
Finland	6	Latvia	1	Slovak Republic	3		

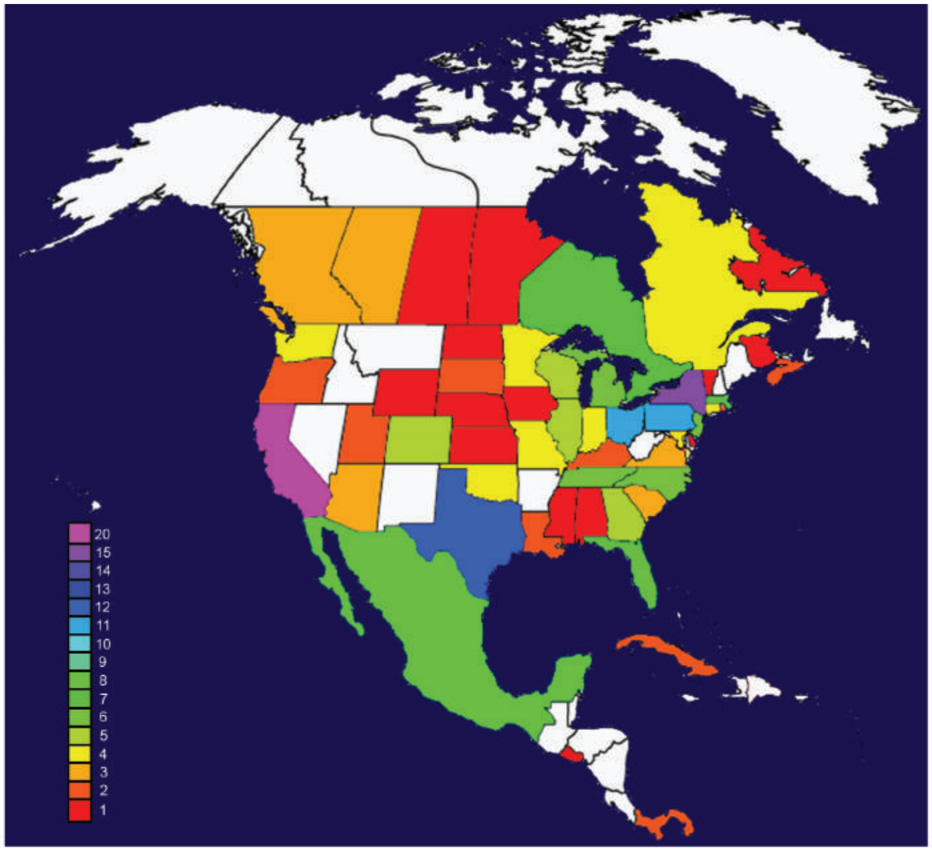
est of the six obtained numbers was selected to normalize all values to a unitary value (Abu-Faraj, 2010). According to the author, the smaller the factor the higher is the outreach of bioengineering/biomedical engineering education per individual per continent. As such, the author reported the following factors: 32.31 for Africa, 6.44 for Asia, 1.68 for Europe, 1.00 for North America, 1.42 for Oceania, and 5.59 for South America.

Upon examining Figure 7 for Africa, the extent of the white shading reflects the fact that this continent lags behind that of North America by a factor of 32.31:1.00. To clarify, if equal samples of 1000 individuals from both continents are considered, then for every 32 individuals receiving bioengineering/biomedical engineering education in North America, only one individual is offered such an education in Africa, resulting in a ratio of approximately 1000:31.

As for Asia (Figure 8), even though it lags behind that of North America by a factor of 6.44:1.00, yet it contains the largest number of universities offering bioengineering/biomedical engineering education; that is, 275 vs. 225. Of particular interest within this continent are the numbers obtained for China (90), Japan (32), India (31), Korea (27), Russian Federation (24), and Turkey (21).

Europe (Figure 9) is comparable with North America with a factor of 1.68:1.00; most prominently are the numbers of programs within the

Figure 10. The mapping of Bioengineering/Biomedical Engineering education in North America. Source: Abu-Faraj, 2010 - Courtesy of Intech Open Access Publisher, Vienna, Austria, EU.



Canada-Alberta	3	USA-Delaware	1	USA-New York	15
Canada-British Columbia	3	USA-District of Columbia	2	USA-North Carolina	6
Canada-Manitoba	1	USA-Florida	8	USA-North Dakota	1
Canada-New Brunswick	1	USA-Georgia	5	USA-Ohio	11
Canada-Newfoundland & Labrador	1	USA-Illinois	5	USA-Oklahoma	4
Canada-Nova Scotia	2	USA-Indiana	4	USA-Oregon	2
Canada-Ontario	7	USA-Iowa	1	USA-Pennsylvania	11
Canada-Quebec	4	USA-Kansas	1	USA-Rhode Island	2
Canada-Saskatchewan	1	USA-Kentucky	2	USA-South Carolina	3
Cuba	2	USA-Louisiana	2	USA-South Dakota	2
El Salvador	1	USA-Maryland	4	USA-Tennessee	6
Mexico	8	USA-Massachusetts	8	USA-Texas	12
Panama	2	USA-Michigan	6	USA-Utah	2
USA-Alabama	1	USA-Minnesota	4	USA-Vermont	1
USA-Arizona	3	USA-Mississippi	1	USA-Virginia	3
USA-California	20	USA-Missouri	4	USA-Washington	4
USA-Colorado	5	USA-Nebraska	1	USA-Wisconsin	5
USA-Connecticut	4	USA-New Jersey	6	USA-Wyoming	1

United Kingdom (26) and Germany (23). It is worth noting that there exists a discrepancy between the number found in this study for Europe, 152, and that of Nagel *et al*. (2007) who reported that there are more than 200 institutions of higher learning in Europe offering academic programs in MBES. This discrepancy requires further investigation.

With regard to North America (Figure 10), the aggregate number of programs within the United

Figure 11. The mapping of Bioengineering/Biomedical Engineering education in Oceania. Source: Abu-Faraj, 2010 - Courtesy of Intech Open Access Publisher, Vienna, Austria, EU.

States of America, totalling to 189 programs, is quite impressive number. This is followed by Canada with a total of 23 programs.

Oceania (Figure 11), although small in population, is also comparable with North America with a factor of 1.42:1.00; however, bioengineering/biomedical engineering education is restricted to Australia and New Zealand.

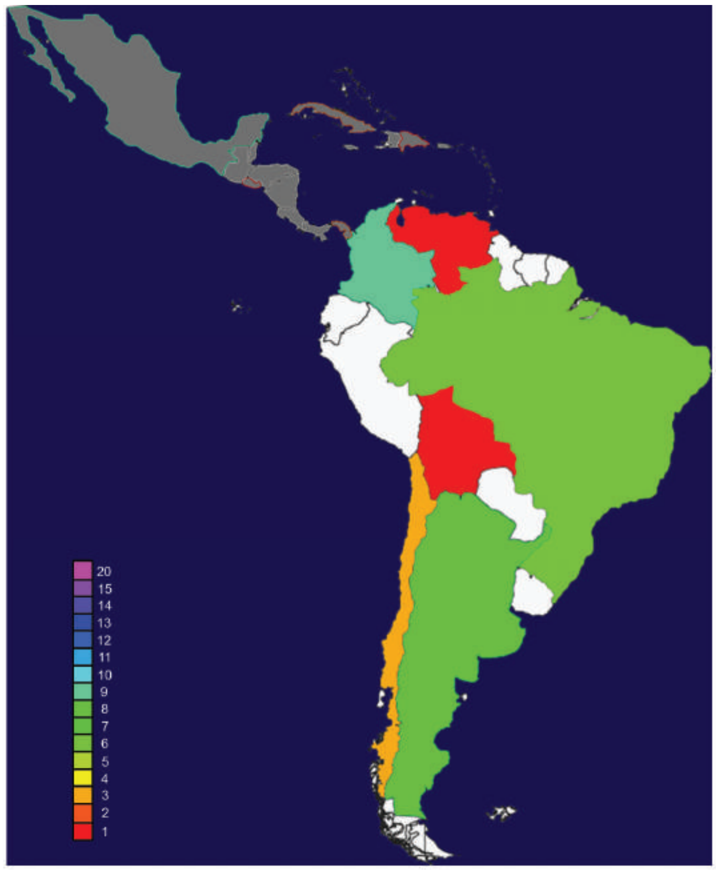
Lastly, even though South America (Figure 12) lags behind North America with a factor of 5.59:1.00, yet it has 29 programs in bioengineering/biomedical engineering ensuring the coverage of 50% of the continent's countries (Abu-Faraj, 2010).

According to the results obtained from '*Project Alexander the Great*', Abu-Faraj concluded that bioengineering/biomedical engineering education is globally undergoing a healthy growth. He added that there are currently 704 programs in bioengineering/biomedical engineering worldwide, offered in 6.73% of the world universities; two numbers that he believes are worth constant monitoring since the world is witnessing a rapid perpetual change in this field (Abu-Faraj, 2010).

The aforementioned conclusion is further supported by the U.S. Department of Labor, Washington, DC, USA, which reported that "the number of biomedical engineering jobs will increase by 31.4 percent through 2010 ... double the rate for all other jobs combined." According to this number, it was forecasted that the overall job growth in this field would average to 15.2 percent by the year 2010 (Anonymous, 1996). This forecast is reflected in Figure 13, which highlights the student enrollment in biomedical engineering within the United States in 1975-2003. The rapid surge in bioengineering/biomedical engineering enrollment that started in 1999, as observed in this figure, is worth noting. In spite of this sizeable growth, employment indicators show that it is unlikely that job opportunities in this field will saturate any time soon.

It is imperative to draw the attention of the reader to the fact that the above forecast was made before the World Financial Crisis of 2007-2011, and which, to date, has displayed no tangible signs of having any impact on bioengineering/biomedical engineering education, yet this matter remains to be appraised.

Figure 12. The mapping of Bioengineering/Biomedical Engineering education in South America. Source: Abu-Faraj, 2010 - Courtesy of Intech Open Access Publisher, Vienna, Austria, EU.



Argentina	9	Brazil	6	Columbia	9	Venezuela	1
Bolivia	1	Chile	3				

Interestingly, the observed rise in the number of students enrolled in Bioengineering/Biomedical Engineering within the United States is complemented with a similar rise in the number of ABET-accredited programs in Bioengineering/Biomedical Engineering, which reached 71 (70 BS/BE and 1 MS) programs in 2008, apart from those that fall under other engineering programs, such as Electrical and Computer Engineering, Figure 14. Although, these figures are U.S.-centric in nature, there is no doubt that they reflect the potential for further growth of this field within the United States, and hence the rest of the world.

Abu-Faraj concluded his study by delineating the relevance of '*Project Alexander the Great*' in the following points (Abu-Faraj, 2010):

1. The inception of a web-based 'world map' in bioengineering/biomedical engineering education for the potential international student desiring to pursue a career in this field.
2. The global networking of bioengineering/biomedical engineering academic and research programs.
3. The promotion of first-class bioengineering/biomedical engineering education and the catalysis of global proliferation of this field.

Figure 13. Undergraduate and graduate students' enrollment in Biomedical Engineering within the United States between 1975 and 2003. Data was reproduced by digitization from the Whitaker Foundation website (Anonymous, 2006c) and extended from Pilkington et al., 1989.

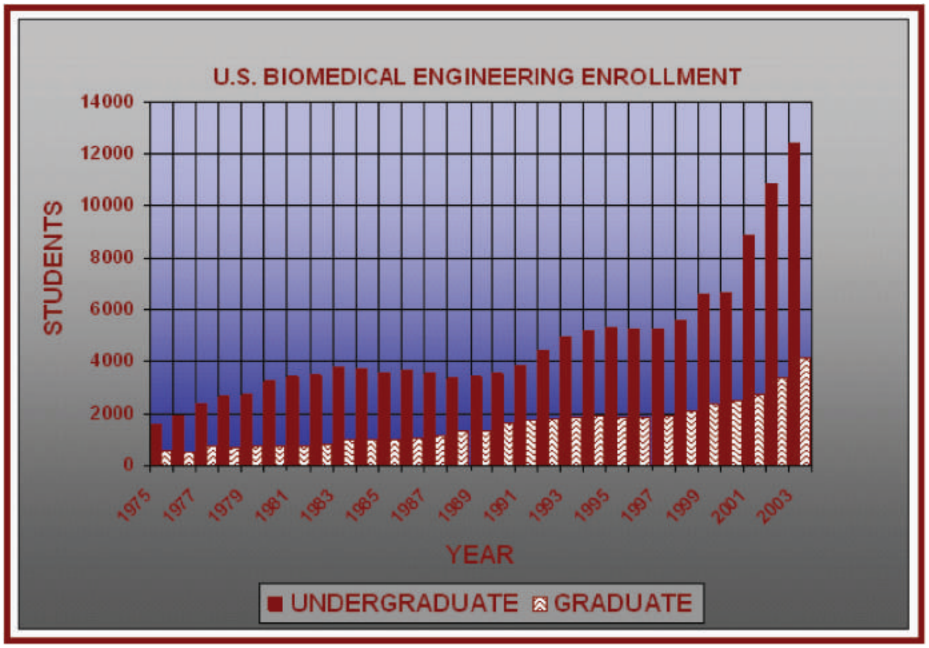
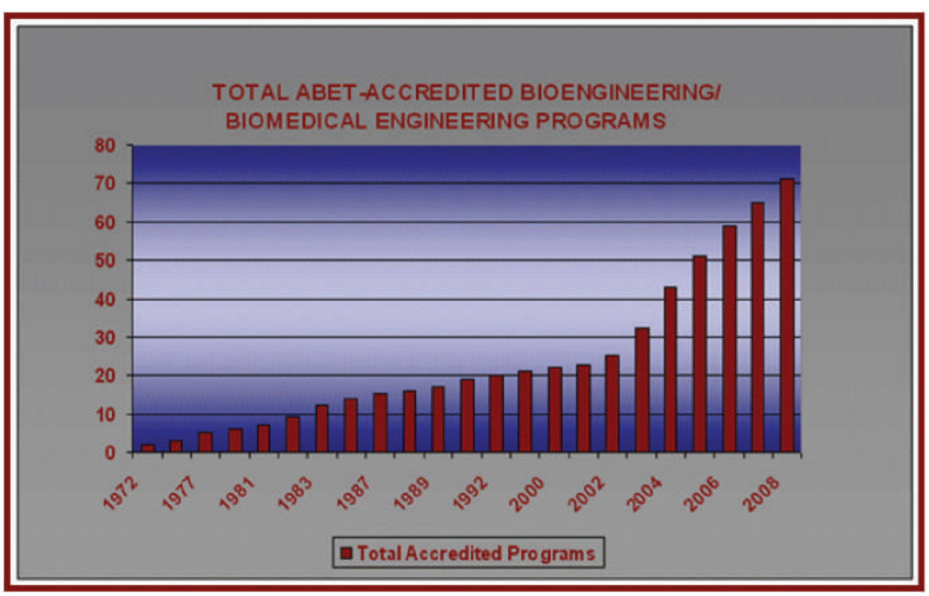


Figure 14. The total number of ABET-accredited Bioengineering/Biomedical Engineering programs within the United States between 1972 and 2008. Data was compiled from the ABET website (ABET, Inc., Baltimore, MD, USA). Available online: http://www.abet.org/AccredProgramSearch/AccreditationSearch.aspx



4. The erection of bridges among educational institutions, industry, and professional societies or organizations involved in bioengineering/biomedical engineering.
5. The catalysis in the establishment of framework agreements for cooperation among the identified academic institutions offering curricula in this field.

1.9. THE FUTURE OF BIOENGINEERING/BIOMEDICAL ENGINEERING EDUCATION

Based on the evolution of the field of Bioengineering/Biomedical Engineering, it is safe to forecast that education in this field will continue to proliferate globally over the next decades, particularly in the developing and transitional countries.

It is expected that academic curricula in this field will undergo further modifications, and perhaps evolutions, oriented towards optimal objectives, which would secure more interaction between institutions of higher learning and industry thus promoting the quality of healthcare and further advancing knowledge in biology, medicine, and engineering. Such modifications have already begun to evolve and even come forth from other competitive yet compatible disciplines. For instance, in 1998 the Massachusetts Institute of Technology (MIT, Cambridge, MA, USA) founded the Department of Biological Engineering with "the mission of defining and establishing a new discipline fusing molecular life sciences with engineering. The goal of this biological engineering discipline is to advance fundamental understanding of how biological systems operate and to develop effective biology-based technologies for applications across a wide spectrum of societal needs including breakthroughs in diagnosis, treatment, and prevention of diseases, in design of novel materials, devices, and processes, and in enhancing environmental health." (Anonymous, 2010). Another example could be drawn from the addition of the term "biomolecular" to the official title of the Department of Chemical and Biomolecular Engineering in the Whiting School of Engineering at Johns Hopkins University (Baltimore, MD, USA) in 2003. This change came as a result of the evolution of Chemical Engineering "a broad and versatile discipline in which chemical engineers work on the development and application of processes that change materials either chemically or physically. This branch of engineering was originally based on the applications of chemistry, combined with the principles of physics and mathematics. Over time, and with increasing speed, it has evolved so that biological sciences and chemistry now fill the position once uniquely held by chemistry." (Anonymous, 2011). Moreover, research and development in the field of Bioengineering/Biomedical Engineering will advance in tandem with science and technology, introducing new frontiers to be added to the current 20 constituent subdivisions of the field. Furthermore, Professional societies and organization will continue to play a vital role in connecting people as well as in the dissemination of knowledge whether through traditional means or through unconventional breakthroughs in technology.

1.10. PROFESSIONAL SOCIETIES AND ORGANIZATIONS

The ensuing selected information pertaining to each society and organization was obtained from its respective website without modification:

ABET

Accreditation Board for Engineering and Technology, Inc., 111 Market Pl., Suite 1050, Baltimore, MD 21202, USA. http://www.abet.org/.

"Engineers' Council for Professional Development (ECPD), established in June 1932 was an engineering professional body dedicated to the education, accreditation, regulation and professional development of the engineering professionals and students in the United States.

Seven engineering societies founded the organization and contributed to its original direction and focus: The American Society of Civil Engineers (ASCE), the American Institute of Mining and Metallurgical Engineers (now the American Institute of Mining, Metallurgical, and Petroleum Engineers), the American Society of Mechanical Engineers (ASME), the American Institute of Electrical Engineers (now IEEE), the Society for the Promotion of Engineering Education (now the American Society for Engineering Education), the American Institute of Chemical Engineers (AIChE), and the National Council of State Boards of Engineering Examiners (now NCEES).

In 1936, ECPD evaluated its first engineering degree programs. Ten years later, the council began evaluating engineering technology degree programs. By 1947, ECPD had accredited 580 undergraduate engineering programs at 133 institutions.

In 1980, ECPD was renamed the Accreditation Board for Engineering and Technology (ABET) to more accurately describe its emphasis on accreditation… In 2005, ABET formally changed its name to ABET, Inc.

ABET's international activities began in 1979… By 1989, ABET was a consultant to both fledgling and established international accreditation boards, a substantial equivalence evaluator of international programs, and a founding member of the multinational Washington Accord… Currently, ABET accredits over 3,100 programs at more than 600 colleges and universities worldwide… ABET has been recognized by the Council for Higher Education Accreditation (CHEA) since 1997.

In 1997, following nearly a decade of development, ABET adopted Engineering Criteria 2000 (EC2000), considered at the time a revolutionary approach to accreditation criteria. EC2000 focused on what is learned rather than what is taught. At its core was the call for a continuous improvement process informed by the specific mission and goals of individual institutions and programs.

Today, … ABET encourages the EC2000 perspective with other accreditation boards and degree programs, promoting global education and worker mobility through agreements like the Washington Accord."

BMES

Biomedical Engineering Society, 8201 Corporate Drive, Suite 1125, Landover, MD 20785-2224, USA. http://www.bmes.org/aws/BMES/pt/sp/home_page.

"In response to the emerging need to provide a society offering equal status to representatives of both biomedical and engineering interests, the Biomedical Engineering Society was incorporated in Illinois on February 1, 1968.

The Society is a 501(c)3 nonprofit professional association, which was established to serve as the lead society and professional home for biomedical engineering and bioengineering students, academics, and professionals. The mission of the Society is to promote and enhance biomedical engineering knowledge worldwide and its utilization for human health and well-being.

Initially, the membership of the Society included 171 founding members and 89 charter members. With the cooperation of the Federation of American Societies for Experimental Biology, the first open meeting of the Biomedical Engineering Society was held at the Ritz-Carlton Hotel in Atlantic City on April 17, 1968… Now, more than 40 years later, BMES membership has grown to nearly 4,000, with almost 100 BMES student chapters and several emerging industry and international chapters.

The Society offers several categories of membership: Fellow, Member, Associate Member, Student Member, Early-Career Member, and Emeritus Member…

BMES annually conducts multiday scientific meetings with oral (platform) and poster presentations and industry and institution exhibits. Because of the Society's emphasis on students, graduate students, and emerging professionals, BMES also hosts student sessions and events, career services, and premeeting workshops, special symposia, and courses.

The Society publishes a monthly peer-reviewed scientific journal, the Annals of Biomedical Engineering (AMBE), and a quarterly peer-reviewed scientific journal, Cellular Biomolecular Engineering (CMBE)… BMES also publishes a monthly online newsletter, Biomedical Engineering News..."

EMBS

Engineering in Medicine and Biology Society, EMBS Executive Office, IEEE, 445 Hoes Lane, Piscataway, NJ 08855-1331 USA. http://www.embs.org/index.html.

Established in 1952, "IEEE Engineering in Medicine and Biology Society (EMBS) is the world's largest international society of biomedical engineers. The organization's 8,200 members reside in some 70 countries around the world… IEEE EMBS members come from everywhere and every walk of life. They work in industry, academic institutions, hospitals, and government agencies… They're interested in bioinformatics, biotechnology, clinical engineering, information technology, instrumentation and measurement, micro and nanotechnology, radiology, and robots. They are researchers and educators, technicians and clinicians; they are the link between science and life science; and they help the modern world work.

IEEE Engineering in Medicine and Biology Society advances the application of engineering sciences and technology to medicine and biology, promotes the profession, provides global leadership for the benefit of its members and humanity, by disseminating knowledge, setting standards, fostering professional development, and recognizing excellence.

With some 119 chapters worldwide, 40 student branch chapters and 27 student clubs, EMBS has a wide variety of chapters and networking opportunities for its members."

IAU

International Association of Universities, IAU Secretariat, UNESCO House, 1, Rue Miollis, 75732 Paris Cedex 15, France. http://www.iau-aiu.net/.

"IAU, founded in 1950, is the UNESCO-based worldwide association of higher education institutions. It brings together institutions and organisations from some 150 countries for reflection and action on common concerns and collaborates with various international, regional and national bodies active in higher education.

The Association aims at giving expression to the obligation of universities and other higher education institutions as social institutions to promote, through teaching, research and services, the principles of freedom and justice, of human dignity and solidarity, and contributes, through international cooperation, to the development of material and moral assistance for the strengthening of higher education generally.

As stated in its Founding Charter IAU's mission is based on the fundamental principles for which every university should stand:

- The right to pursue knowledge for its own sake and to follow wherever the search for truth may lead;
- The tolerance of divergent opinion and freedom from political interference.

The overall goals of IAU are both internal and external:

- IAU links up its Members, offering them quality services, networking and collective action.

- The Association speaks on behalf of universities, other higher education institutions and associations and represents their concerns and interests in public debate and to outside partners.

Both of these complementary goals are pursued through future oriented collective action, including conferences and meetings, information services, policy discussion, research and publications.

By encouraging Members to work together, IAU

- Facilitates the exchange of experience and learning and fosters cooperation;
- Restates and defends the academic values and principles that underlie and determine the proper functioning of universities and other higher education institutions;
- Upholds and contributes to the development of a long-term vision of universities' role and responsibilities in society;
- Voices the concerns for higher education with regard to policies of international bodies such as UNESCO, the World Bank and others;
- Contributes to a better understanding of current trends and policy developments through analysis, research and debate;
- Provides comprehensive and authoritative information on higher education systems, institutions and qualifications worldwide.

IBE

The Institute of Biological Engineering, 3493 Lansdowne Dr., Suite 2, Lexington, Kentucky 40517, USA. http://ibe.org/.

"The Institute of Biological Engineering (IBE) is a professional organization which encourages inquiry and interest in biological engineering. IBE supports:

- Scholarship in education, research and service
- Professional standards for engineering practices
- Professional and technical development of biological engineering
- Interactions among academia, industry and government
- Public understanding and responsible uses of biological engineering products.

Through publications, meetings, distribution of information and services, IBE encourages:

- Cooperation among engineers, scientists, technologists and allied professionals
- Timely availability of new knowledge and technology
- Collaboration in education, research and economic activities worldwide
- Active promotion and growth of its members."

IBE

International Bureau of Education, UNESBO-IBE, Geneva, Switzerland. http://www.ibe.unesco.org/en.html.

"The IBE was founded in Geneva as a private, non-governmental organization in 1925. Its aims were to centralize documentation related to public and private education, to take an interest in scientific research in the educational field, and to serve as a coordinating centre for institutions and societies concerned with education.

In 1929, under new statutes, the IBE extended membership to governments, while it remained open to public institutions and international organizations. It thus became the first intergovernmental organization in the field of education.

Since 1934, the IBE has organized the International Conference on Public Education (now the International Conference on Education) which, from 1946 onwards, was convened together with the United Nations Educational, Scientific and Cultural Organization (UNESCO), founded in 1945.

In 1969, the IBE became an integral part of UNESCO while retaining intellectual and functional autonomy. In 1999 the IBE became the UNESCO institute responsible for educational contents, methods and teaching/learning strategies through curriculum development."

IEEE

Institute of Electrical and Electronics Engineers, IEEE Corporate Office, 3 Park Avenue, 17th Floor, New York, NY 10016-5997 USA. http://www.ieee.org/index.html.

"IEEE, an association dedicated to advancing innovation and technological excellence for the benefit of humanity, is the world's largest technical professional society. It is designed to serve professionals involved in all aspects of the electrical, electronic and computing fields and related areas of science and technology that underlie modern civilization…

In the spring of 1884, a small group of individuals in the electrical professions met in New York. They formed a new organization to support professionals in their nascent field and to aid them in their efforts to apply innovation for the betterment of humanity—the American Institute of Electrical Engineers, or AIEE for short. That October the AIEE held its first technical meeting in Philadelphia, Pa. Many early leaders, such as founding President Norvin Green of Western Union, came from telegraphy. Others, such as Thomas Edison, came from power, while Alexander Graham Bell represented the newer telephone industry. As electric power spread rapidly across the land—enhanced by innovations such as Nikola Tesla's AC Induction Motor, long distance AC transmission and large-scale power plants, and commercialized by industries such as Westinghouse and General Electric—the AIEE became increasingly focused on electrical power and its ability to change people's lives through the unprecedented products and services it could deliver. There was a secondary focus on wired communication, both the telegraph and the telephone. Through technical meetings, publications, and promotion of standards, the AIEE led the growth of the electrical engineering profession, while through local sections and student branches, it brought its benefits to engineers in widespread places.

A new industry arose beginning with Guglielmo Marconi's wireless telegraphy experiments at the turn of the century. What was originally called "wireless" became radio with the electrical amplification possibilities inherent in the vacuum tubes which evolved from John Fleming's diode and Lee de Forest's triode. With the new industry came a new society in 1912, the Institute of Radio Engineers. The IRE was modeled on the AIEE, but was devoted to radio, and then increasingly to electronics. It, too, furthered its profession by linking its members through publications, standards and conferences, and encouraging them to advance their industries by promoting innovation and excellence in the emerging new products and services.

Through the help of leadership from the two societies, and with the applications of its members' innovations to industry, electricity wove its way—decade by decade—more deeply into every corner of life—television, radar, transistors, computers. Increasingly, the interests of the societies overlapped. Membership in both societies grew, but beginning in the 1940s, the IRE grew faster and in 1957 became the larger group. On 1 January 1963, The AIEE and the IRE merged to form the Institute of Electrical and Electronics Engineers, or IEEE. At its formation, the IEEE had 150,000 members, 140,000 of whom were in the United States.

By the early 21st Century, IEEE served its members and their interests with 38 societies; 130 journals, transactions and magazines; more 300 conferences annually; and 900 active standards.

Since that time, … IEEE's fields of interest expanded well beyond electrical/electronic engineering and computing into areas such as micro- and nanotechnology, ultrasonics, bioengineering, robotics, electronic materials, and many others. Electronics became ubiquitous—from jet cockpits to industrial robots to medical imaging. As technologies and the industries that developed them increasingly transcended national boundaries, IEEE kept pace, becoming a truly global institution which used the innovations of the practitioners it represented in order to enhance its own excellence in delivering products and services to members, industries, and the public at large. Publications and educational programs were delivered online, as were member services such as renewal and elections. By 2010, IEEE had over 395,000 members in 160 countries. Through its worldwide network of geographical units, publications, web services, and conferences, IEEE remains the world's largest technical professional association.

IEEE's core purpose is to foster technological innovation and excellence for the benefit of humanity.

IEEE will be essential to the global technical community and to technical professionals everywhere, and be universally recognized for the contributions of technology and of technical professionals in improving global conditions."

IFMBE

International Federation for Medical and Biological Engineering, IFMBE Secretary-General: Prof. Dr. Ratko Magjarevic, Faculty of Electrical Engineering and Computing, University of Zagreb, Unska 3, HR-10000 Zagreb, Croatia. http://www.ifmbe.org/index2.html.

"In 1959 a group of medical engineers, physicists and physicians met at the 2nd International Conference of Medical and Biological Engineering, in the UNESCO Building, Paris, France to create an organization entitled International Federation for Medical Electronics and Biological Engineering. At that time there were few national biomedical engineering societies and workers in the discipline joined as Associates of the Federation. Later, as national societies were formed, these societies became affiliates of the Federation. In the mid-sixties, the name was shortened to International Federation for Medical and Biological Engineering…

As the Federation grew, its constituency and objectives changed. During the first ten years of its existence, clinical engineering became a viable subdiscipline with an increasing number of members employed in the health care area. The IFMBE mandate was expanded to represent those engaged in Research and Development and in Clinical Engineering. The latter category now represents close to half of the total membership.

In October 2006, the Federation now has an estimated 120,000 members in 58 affiliated organizations. The category Honorary Life Member is given to individuals who have served the Federation in various ways as affiliate members.

The IFMBE has also achieved a close association with the International Organization of Medical Physics. Its international conferences, commencing with the 11th in 1976 have been aligned or combined with those of the IOMP. The two international bodies have established an International Union for Physical and Engineering Sciences in Medicine.

The mission of the IFMBE is to encourage, support, represent and unify the world-wide Medical and Biological Engineering community in order to promote health and quality of life through advancement of research, development, application and management of technology.

Goals:

1. To function as the leader in representing the international community of medical and biological engineering; …
2. To foster the creation, dissemination and application of medical and biological engineering knowledge and the management of

technology for improved health and quality of life…

3. To promote the development of the medical and biological engineering profession, and the recognition and awareness of the profession by the public…
4. To advance collaboration between national and transnational societies, industry, government and non-governmental organizations engaged in health care and in biomedical research and its applications…
5. To recommend policies and provide guidelines in appropriate professional, educational and ethical areas…
6. To enable IFMBE to achieve its goals effectively, optimize the organizational structure and communication and enhance its finances."

NIH

National Institutes of Health, 9000 Rockville Pike, Bethesda, MD 20892, USA. http://www.nih.gov/.

"The NIH traces its roots to 1887, when a one-room laboratory was created within the Marine Hospital Service (MHS), predecessor agency to the U.S. Public Health Service (PHS). The MHS had been established in 1798 to provide for the medical care of merchant seamen. One clerk in the Treasury Department collected twenty cents per month from the wages of each seaman to cover costs at a series of contract hospitals. In the 1880s, the MHS had been charged by Congress with examining passengers on arriving ships for clinical signs of infectious diseases, especially for the dreaded diseases cholera and yellow fever, in order to prevent epidemics. During the 1870s and 1880s, moreover, scientists in Europe presented compelling evidence that microscopic organisms were the causes of several infectious diseases. In 1884, for example, Koch described a comma-shaped bacterium as the cause of cholera.

Officials of the MHS followed these developments with great interest. In 1887, they authorized Joseph J. Kinyoun, a young MHS physician trained in the new bacteriological methods, to set up a one-room laboratory in the Marine Hospital at Stapleton, Staten Island, New York. Kinyoun called this facility a "laboratory of hygiene" in imitation of German facilities and to indicate that the laboratory's purpose was to serve the public's health. Within a few months, Kinyoun had identified the cholera bacillus in suspicious cases and used his Zeiss microscope to demonstrate it to his colleagues as confirmation of their clinical diagnoses. "As the symptoms . . . were by no means well defined," he wrote, "the examinations were confirmatory evidence of the value of bacteria cultivation as a means of positive diagnosis."

NIH's mission is to seek fundamental knowledge about the nature and behavior of living systems and the application of that knowledge to enhance health, lengthen life, and reduce the burdens of illness and disability.

The goals of the agency are:

- To foster fundamental creative discoveries, innovative research strategies, and their applications as a basis for ultimately protecting and improving health;
- To develop, maintain, and renew scientific human and physical resources that will ensure the Nation's capability to prevent disease;
- To expand the knowledge base in medical and associated sciences in order to enhance the Nation's economic well-being and ensure a continued high return on the public investment in research; and
- To exemplify and promote the highest level of scientific integrity, public accountability, and social responsibility in the conduct of science.

In realizing these goals, the NIH provides leadership and direction to programs designed to improve the health of the Nation by conducting and supporting research:

- In the causes, diagnosis, prevention, and cure of human diseases;
- In the processes of human growth and development;
- In the biological effects of environmental contaminants;
- In the understanding of mental, addictive and physical disorders; and
- In directing programs for the collection, dissemination, and exchange of information in medicine and health, including the development and support of medical libraries and the training of medical librarians and other health information specialists."

NSF

National Science Foundation, 4201 Wilson Boulevard, Arlington, VA 22230, USA. http://www.nsf.gov/.

"The National Science Foundation (NSF) is an independent federal agency created by Congress in 1950 'to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…' With an annual budget of about $6.9 billion (FY 2010), we are the funding source for approximately 20 percent of all federally supported basic research conducted by America's colleges and universities. In many fields such as mathematics, computer science and the social sciences, NSF is the major source of federal backing.

We fulfill our mission chiefly by issuing limited-term grants -- currently about 10,000 new awards per year, with an average duration of three years -- to fund specific research proposals that have been judged the most promising by a rigorous and objective merit-review system. Most of these awards go to individuals or small groups of investigators. Others provide funding for research centers, instruments and facilities that allow scientists, engineers and students to work at the outermost frontiers of knowledge.

NSF's goals--discovery, learning, research infrastructure and stewardship--provide an integrated strategy to advance the frontiers of knowledge, cultivate a world-class, broadly inclusive science and engineering workforce and expand the scientific literacy of all citizens, build the nation's research capability through investments in advanced instrumentation and facilities, and support excellence in science and engineering research and education through a capable and responsive organization…

Many of the discoveries and technological advances have been truly revolutionary. In the past few decades, NSF-funded researchers have won more than 180 Nobel Prizes as well as other honors too numerous to list. These pioneers have included the scientists or teams that discovered many of the fundamental particles of matter, analyzed the cosmic microwaves left over from the earliest epoch of the universe, developed carbon-14 dating of ancient artifacts, decoded the genetics of viruses, and created an entirely new state of matter called a Bose-Einstein condensate.

NSF also funds equipment that is needed by scientists and engineers but is often too expensive for any one group or researcher to afford. Examples of such major research equipment include giant optical and radio telescopes, Antarctic research sites, high-end computer facilities and ultra-high-speed connections, ships for ocean research, sensitive detectors of very subtle physical phenomena and gravitational wave observatories.

Another essential element in NSF's mission is support for science and engineering education, from pre-K through graduate school and beyond. The research we fund is thoroughly integrated with education to help ensure that there will always be plenty of skilled people available to work in new and emerging scientific, engineering and technological fields, and plenty of capable teachers to educate the next generation.

No single factor is more important to the intellectual and economic progress of society, and to the enhanced well-being of its citizens, than the continuous acquisition of new knowledge. NSF is proud to be a major part of that process.

Specifically, the Foundation's organic legislation authorizes us to engage in the following activities:

a. Initiate and support, through grants and contracts, scientific and engineering research and programs to strengthen scientific and engineering research potential, and education programs at all levels, and appraise the impact of research upon industrial development and the general welfare.
b. Award graduate fellowships in the sciences and in engineering.
c. Foster the interchange of scientific information among scientists and engineers in the United States and foreign countries.
d. Foster and support the development and use of computers and other scientific methods and technologies, primarily for research and education in the sciences.
e. Evaluate the status and needs of the various sciences and engineering and take into consideration the results of this evaluation in correlating our research and educational programs with other federal and non-federal programs.
f. Provide a central clearinghouse for the collection, interpretation and analysis of data on scientific and technical resources in the United States, and provide a source of information for policy formulation by other federal agencies.
g. Determine the total amount of federal money received by universities and appropriate organizations for the conduct of scientific and engineering research, including both basic and applied, and construction of facilities where such research is conducted, but excluding development, and report annually thereon to the President and the Congress.
h. Initiate and support specific scientific and engineering activities in connection with matters relating to international cooperation, national security and the effects of scientific and technological applications upon society.
i. Initiate and support scientific and engineering research, including applied research, at academic and other nonprofit institutions and, at the direction of the President, support applied research at other organizations.
j. Recommend and encourage the pursuit of national policies for the promotion of basic research and education in the sciences and engineering. Strengthen research and education innovation in the sciences and engineering, including independent research by individuals, throughout the United States.
k. Support activities designed to increase the participation of women and minorities and others underrepresented in science and technology.

NSF is divided into the following seven directorates that support science and engineering research and education: Biological Sciences, Computer and Information Science and Engineering, Engineering, Geosciences, Mathematics and Physical Sciences, Social, Behavioral and Economic Sciences, and Education and Human Resources.

Each year, NSF supports an average of about 200,000 scientists, engineers, educators and students at universities, laboratories and field sites all over the United States and throughout the world, from Alaska to Alabama to Africa to Antarctica. You could say that NSF support goes 'to the ends of the earth' to learn more about the planet and its inhabitants, and to produce fundamental discoveries that further the progress of research and lead to products and services that boost the economy and improve general health and well-being."

VaNTH-ERC

Vanderbilt - Northwestern - Texas - Harvard/MIT Engineering Research Center, VaNTH-ERC Headquarters, Vanderbilt University, Room 5824, Stevenson Center, Nashville, TN 37235, USA. http://www.vanth.org/.

"In October 1999, the National Science Foundation funded the Vanderbilt-Northwestern-Texas-Harvard/MIT Engineering Research Center. Our vision is to transform bioengineering education to produce adaptive experts by developing, implementing and assessing educational processes, materials and technologies that are readily accessible and widely disseminated. VaNTH will be a working model for how multidisciplinary, multi-institutional groups can define an approach to developing & testing curricula for rapidly evolving knowledge bases.

Our major deliverables all support the development, implementation and assessment of educational processes, materials and technologies. In addition to those deliverables posited in the question, we also seek to provide materials that guide curricular development, assessment that supports the development of adaptive expertise, and processes that promote cultural change. Our specific deliverables include:

- Exemplar granules, modules, mosaics, and courses in a variety of bioengineering domains (educational materials)
- Methods and guidelines for efficiently developing HPL-informed modules (roadmap)
- Learning Technology platforms for granule, module, mosaic, and course development (for example, Socratic ASK, Indie, CAPE, eLCMS, eLMS)
- Guidelines for developing formative and summative assessment plans
- Domain taxonomies and core competencies
- Curricular recommendations, examples, and tools
- A way to transmit VaNTH culture without turning all faculty into expert module developers (tools for faculty development)

Our overall strategy is to bring learning scientists, assessment experts, learning technologists and bioengineering domain experts together into an integrated effort to develop an educational system centered on challenge-based instruction with major support from technology. This effort has required a significant re-thinking of the structure of knowledge in bioengineering and a selection of principles from learning science that are likely to have significant impact on bioengineering education. Our strategy has been to organize four highly interactive research thrusts in learning sciences, assessment and evaluation, learning technology and bioengineering domains, and education and industrial/practitioner partners programs.

VaNTH ERC is dedicated to recruiting and training postdoctoral students, graduate students and undergraduate students from the learning sciences, computer sciences and bioengineering on the latest educational theories and practical applications to the field of bioengineering education. The center also strives to bring training opportunities to present bioengineering faculty. K-12 educators and students benefit from the efforts of VaNTH to raise awareness of the field of bioengineering and to provide opportunities for students and instructors to use VaNTH teaching materials.

The goals of the education program are:

Goal 1: Attract and retain highly qualified postdoctoral students, graduate students and undergraduate students to participate in the education activities of VaNTH.

Goal 2: Develop and disseminate modules, workshop materials, seminars and courses that emphasize training in basic elements of education for bioengineering graduate students and university educators. A major requirement of bioengineering professors is that they teach. Little or no preparation is provided in this area, and yet there is an extensive educational research knowledge base that can inform their teaching. The ultimate goal is to provide current bioengineering professors, graduate students, and postdoctoral students with knowledge of current research-based effective practices in education so that they may be better teachers in their field.

Goal 3: Provide training in basic HPL Philosophy and Methodology to those who will be developing and delivering VaNTH HPL educational materials. This is an integrated effort between the Education Program and the LS, LT and AE thrusts. Recipients of this training include professors, post-doctoral students, graduate teaching assistants, VaNTH graduate students, REU students, RET K-12 teachers, and students involved in developing modules.

Goal 4: Ensure that each VaNTH student is properly supervised, has adequate industrial and professional exposure, and is an integral member of an interdisciplinary research team.

Goal 5: Maintain a database of ERC students and their related activities.

Goal 6: Inform teachers, learners and the general public about the learning science principles embodied in "How People Learn" and help teachers apply HPL principles in their domains.

Goal 7: Use VaNTH resources to raise awareness of biomedical engineering in general, particularly in K-12 students, and to increase the quality of the students going into bio/medical engineering."

Whitaker-IIE

Whitaker International Fellows and Scholars Program, U.S. Student Programs Division, Institute of International Education, 809 United Nations Plaza, New York, NY 10017, USA. http://www.whitaker.org/ and http://www.iie.org/.

"The Whitaker Foundation was created and funded by U.A. Whitaker upon his death in 1975. His wife, Helen, who shared in his philanthropy during his lifetime, joined him in bequeathing a significant portion of her estate to the Foundation when she died in 1982. Throughout its history, the Foundation primarily supported interdisciplinary medical research, with a focus on biomedical engineering. It contributed more than $700 million to universities and medical schools to support faculty research, graduate students, program development, and construction of facilities. Most of its efforts were directed toward the establishment and enhancement of formal educational programs and the support of especially talented students and faculty.

After 30 years of support for the development of biomedical engineering in the United States, The Whitaker Foundation felt that it had achieved its primary objective of helping the American biomedical engineering field grow into a legitimate widespread discipline. In 2006, the Foundation ceased operations, and committed its remaining funds to a grant program focused on strengthening international collaborative links between young leaders in BME worldwide. Under the guidance of the Institute of International Education, the Whitaker International Fellows and Scholars Program is designed to bring international experience and insight to the field of biomedical engineering."

"The Institute of International Education (IIE) is a world leader in the international exchange of people and ideas. Founded in 1919 as an independent, not-for-profit organization, IIE works to solve global problems and to foster mutual understanding among the peoples of the world.

Our mission is to:

- Promote closer educational relations between the people of the United States and other countries;

- Increase the number of students, scholars, and professionals who have the opportunity to study, teach, and conduct research outside of their own countries;
- Strengthen and internationalize institutions of higher learning throughout the world;
- Foster sustainable development through training and technical assistance programs; and
- Partner with corporations, foundations, and governments in finding and developing people able to think and work on a global basis.

On an annual basis, the Institute manages more than 250 programs, including the Fulbright Student and Scholar Programs, which IIE has administered on behalf of the U.S. Department of State since 1946. Dedicated to the goal of Opening Minds to the World and the creation of a new generation of global citizens, IIE programs benefit approximately 20,000 men and women from 175 nations each year. Our sponsors include the U.S. Department of State, the U.S. Agency for International Development (USAID), major philanthropic foundations, private and public corporations, foreign governments, and numerous individuals.

The Institute is strongly committed on behalf of The Whitaker Foundation to continuing to contribute to the career development of future leaders in the field of biomedical engineering, fostering greater international cooperation within the biomedical engineering community, and honoring the commitment of Mr. Whitaker… Building on the vision of Mr. Whitaker, the Whitaker International Fellows and Scholars Program will help a new generation of American biomedical engineers gain essential international experience and become true global citizens."

WHO

World Health Organization, Avenue Appia 20, 1211 Geneva 27, Switzerland. http://www.who.int/en/.

"When diplomats met to form the United Nations in 1945, one of the things they discussed was setting up a global health organization. WHO's Constitution came into force on 7 April 1948 – a date we now celebrate every year as World Health Day.

WHO is the directing and coordinating authority for health within the United Nations system. It is responsible for providing leadership on global health matters, shaping the health research agenda, setting norms and standards, articulating evidence-based policy options, providing technical support to countries and monitoring and assessing health trends.

WHO fulfils its objectives through its core functions:

- Providing leadership on matters critical to health and engaging in partnerships where joint action is needed;
- Shaping the research agenda and stimulating the generation, translation and dissemination of valuable knowledge;
- Setting norms and standards and promoting and monitoring their implementation;
- Articulating ethical and evidence-based policy options;
- Providing technical support, catalysing change, and building sustainable institutional capacity; and
- Monitoring the health situation and assessing health trends.

These core functions are set out in the 11th General Programme of Work, which provides the framework for organization-wide programme of work, budget, resources and results. Entitled 'Engaging for health', it covers the 10-year period from 2006 to 2015."

1.11. CHAPTER SUMMARY

Bioengineering/biomedical engineering education could be defined as a social process whereby accrued knowledge, expertise, and values pertaining to an amalgam of engineering sciences and biomedical sciences are disseminated throughout generations. Bioengineering/biomedical engineering education has been evolving and proliferating since the late 1950's, and is globally undergoing a healthy growth. There are currently 704 programs in bioengineering/biomedical engineering worldwide, offered in 6.73% of the world universities. These programs are somewhat diverse and vary in their academic content, as well as within the different tracks constituting the various areas of bioengineering/biomedical engineering: artificial organs; assistive technology and rehabilitation engineering; bioelectromagnetism; bioethics; biomaterials; biomechanics; biomedical instrumentation; biomedical sensors; bionanotechnology; biorobotics and biomechatronics; biotechnology; clinical engineering; medical and bioinformatics; medical and biological analysis; medical imaging; neural engineering; physiological systems modeling, simulation, and control; prosthetic and orthotic devices; and tissue engineering and regenerative medicine. The apparent growth of bioelectromagnetism, bioethics, biorobotics and biomechatronics, which constitute areas not found on Bronzino's early list of 15 key divisions of Biomedical Engineering (Bronzino, 2005; Bronzino 2006), is a direct example of the expansion of this field.

This chapter began with a formal definition of bioengineering/biomedical engineering education and an in-depth overview of its evolution. This was followed by a detailed description of state-of-the-art curriculum philosophies, an insight into existing academic curricula, and recommendations about career development. The chapter ended with an analytical comprehensive study on the world promulgation of bioengineering/biomedical engineering education with a forecast of the future of bioengineering/biomedical engineering education.

This chapter is not only addressed to the international bioengineering/biomedical engineering researchers, faculty, and university/college students, but it is intended to provide a set of strategies and recommendations to be pursued by individuals and/or entities seeking to plan and design careers and/or curricula in this field, as well as in research and development (R&D) for research scientists and practitioners in bioengineering/biomedical engineering, and other closely-related vocational professions.

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ENDNOTES

[1] HPL: How People Learn

[2] LS: Learning Science

[3] LT: Learning Technology

[4] AE: Assess and Evaluate

[5] REU: Research Experiences for Undergraduates

[6] RET K-12: Research Experiences for Teachers

‡ Uniform Resource Locators (URL) were accessed on December 23, 2010.