24

Project Alexander the Great: An Analytical Comprehensive Study on the Global Spread of Bioengineering/Biomedical Engineering Education

Ziad O. Abu-Faraj, Ph.D.
American University of Science and Technology
Beirut,
Lebanon

1. Introduction

Bioengineering/Biomedical Engineering is globally considered as one of the most acclaimed fields in science and technology, and has been a primer for advancements in medicine and biology. Recently, healthcare practices have been guided towards new emerging frontiers, including, among others, functional medical imaging, regenerative medicine, nanobiomedicine, and artificial sensory substitution. On the other hand, bioengineering/biomedical engineering education has been evolving and proliferating since the late 1950's, and is undergoing advancement in leading academic institutions worldwide (Harris *et al.*, 2002). 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, particularly in developing and transitional countries. 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; 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.

Notwithstanding these advancements in Bioengineering/Biomedical Engineering, there still exist several shortcomings related to the lack of 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. These shortcomings have brought forth the formation of “the right hand not knowing what the left hand is doing” syndrome among the constituting entities. Thus, in order to enhance the spread of the said field, and strongly contribute to its solidification, these deficiencies await to be appropriately rectified. There is no doubt that there exists awareness within the bioengineering/biomedical engineering community of the aforementioned shortcomings; however, 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.

The above mentioned 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. Consequently, this study, bearing the name 'Project Alexander the Great', was designed with an attempt to effectively augment the remedy of this syndrome.

Project Alexander the Great is an original study on the global spread of bioengineering/biomedical engineering education (Abu-Faraj, 2008a). This endeavor began in September 2007 by the Department of Biomedical Engineering at the American University of Science & Technology (AUST, Beirut, Lebanon). The objectives of this project 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. 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.

The provided information is essential, up-to-date, and could be used by the following bioengineering/biomedical engineering target audience: students, faculty, research scientists, and practitioners. In addition to other closely related vocational professions, such as industry, accreditation agencies, professional societies, academic institutions of higher education, ministries of higher education, and other governmental agencies.

Before expounding, the reader's attention is drawn to the fact that this chapter refers to bioengineering and biomedical engineering interchangeably. Katona emphasized 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).

2. Background

An early study pertaining to the academic growth of biomedical engineering as a new career was conducted by Schwartz and Long (1975). This study was based on a 1974 survey around biomedical engineering education, and was jointly conducted by the American Society for Engineering Education and the Engineering in Medicine and Biology group of the IEEE. The objective of this survey was to "identify all the engineering schools in the U.S. having Biomedical Engineering degrees, options or programs". This survey utilized a questionnaire that was administered at 222 engineering schools, and whose major findings as reported by the authors are presented in Table 1.

Potvin *et al.* (1981) conducted a quantitative study about biomedical engineering education comparable with that reported by Schwartz and Long (1975). However, this study utilized an in-depth survey questionnaire that was modified from the one used in 1974, and was distributed to 251 engineering schools in the United States.

Total U.S. engineering schools surveyed (early months of 1974)	**222**
Schools having degrees or programs in Biomedical Engineering (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

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

The new questionnaire covered enrolment, courses, and degrees data for the academic year 1979-1980, as well as 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.

The study was sponsored by the Education Committees of four societies: 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.

In 2002, a web-based directory of 102 universities with biomedical engineering programs within the United States was released by the IEEE Engineering in Medicine and Biology Society, Piscataway, NJ, USA (Anonymous, 2002). Four years later, the Whitaker Foundation, Arlington, VA, USA, published an on-line biomedical engineering curriculum database covering 119 programs (Anonymous, 2006).

Then, Nagel *et al.* (2007) published a comprehensive document on medical and biological engineering and science in the higher educational system in Europe. The document began with an elucidation of the Bologna Declaration, signed on June 19, 1999, and its objectives, which subsequent to their implementation have led to the Bologna Process; a European reform process aiming at establishing a European Higher Education Area (EHEA) by 2010.

The authors reported that, in compliance with the European Union (EU) list of priorities, the Bologna movement provoked the European Medical and Biological Engineering and Science (MBES) community to establish their 'Higher Education Area' by pursuing the following guidelines that they later adopted as their target objectives: i) "harmonizing the educational programs"; ii) "specifying minimum qualifications"; and iii) "establishing criteria for an efficient quality control of education, training, and lifelong learning".

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

Table 2. Summary of reported results from Potvin *et al.* (1981).

Within the same context, the authors reported that more than 200 institutions of higher learning in Europe offer academic programs in MBES at the three levels of education: bachelor, master, and doctoral. Additionally, the authors emphasized the lack of international coordination with regard to “contents and required outcome qualifications”. Notwithstanding this fact, they reported that the interactions in biomedical engineering education between Europe and the United States have been strong despite the differing educational environments. The authors continued by stating that starting 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, in 2004, a Europe-wide participation project under the name 'BIOMEDEA' was conceived in order to attain the above said objectives as has been described in Biomedical Engineering Education in Europe – Status Reports (Nagel, 2005). According to these reports, BIOMEDEA, which is mainly sponsored by the International Federation for Medical and Biological Engineering, IFMBE, Zagreb, Croatia, has been progressing in a productive manner and that 80 European academic institutions had participated in the three meetings that had taken place. Moreover, agreements had been reached 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."

3. Materials and methods

The initial phase of Project Alexander the Great was to create a database of the academic institutions offering bioengineering/biomedical engineering education. Accordingly, a survey was conducted on all 10453 universities recognized by the International Association of Universities, UNESCO, Paris, France (Anonymous, 2007a), spread among the 193 member states of the United Nations, New York, NY, USA, within the six continents. Table 3 depicts the classifications comprising the database that was created thereof. A 0.06125% discrepancy exists 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.

A world-wide-web search, using Google's search engine, Google Inc., Mountain View, CA, USA, was initiated, by continent. Once an institution was identified with a bioengineering/biomedical engineering program, the department's name, address, Uniform Resource Locator (URL), year established, and director's name and coordinates were gathered. Because of the scale and the perseverance required to gather the desired data, a methodical search procedure was deemed necessary and accordingly was set and implemented. This procedure consisted of two iterations explained herein.

The main iteration was to utilize the web. A cut-off limit of 15 minutes was set for the search of whether or not an academic institution had a bioengineering/biomedical engineering program, after which the search proceeded to the next institution. This approach was found mandatory in order to avoid any blockage that may unnecessarily hinder the process. Instances of such hindrances include, but not limited to, language barriers, weak website design, and no or poor internet accessibility. Subsequent to this iteration, the success rate was calculated as the ratio of the number of successes to that of failures. A *success* was coined with the ability to connect, confirm (existence or no existence), and acquire information; while, *failure* meant the inability to connect or no information.

A complementary iteration, aiming at contacting the pertinent embassies/consulates/ministries of higher education, was executed at the end of the first iteration in order to assert the study's findings. This iteration served to boost the success rate.

Moreover, the possibility of having a bioengineering/biomedical engineering program erroneously marked as 'failure' is not considered problematic, because of the obtained high

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**

Table 3. 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).

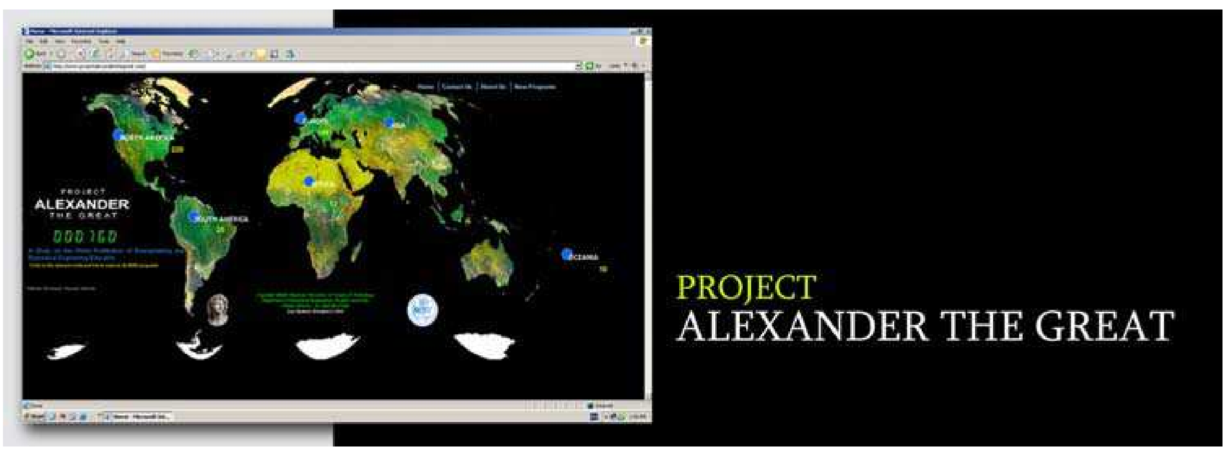


Fig. 1. The front side of an early flyer made to promote Project Alexander the Great.

rate of success, and which could be alleviated by having the concerned academic institution filling out and submitting an *e*-form, which is provided on the project's website, whose URL is www.projectalexanderthegreat.com. Figure 1 shows an early flyer used to promote the project in regional and international assemblies of bioengineering/biomedical engineering.

4. Results and discussion

Statistical results pertaining to the distribution of bioengineering/biomedical engineering education in the six continents are presented in Table 4. 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. The obtained *success* rates for South America, Oceania, North America, and Europe strongly support the methodology implemented in Project Alexander the Great. With regard to those obtained for Africa and Asia, which are considered satisfactory, there are several possible reasons behind these numbers. The difficulties encountered in this project include, 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. In any case, encountered *failures* are expected to diminish with time as long as the sustainability of Project Alexander the Great is maintained.

Table 4 contains 19 items with data pertaining to the six continents. For ease of navigation, 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 the number of universities offering curricula in bioengineering/biomedical engineering, as depicted in Figure 2, there is good evidence that education in this field has globally proliferated. What is worth noting, however, is the fact that the aforementioned numbers are clustered within each continent as depicted in the percent of countries in continent offering bioengineering/biomedical engineering: 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.

Nevertheless, an appraisal of the evolution and proliferation of bioengineering/biomedical engineering as a field of study, in a chronological order since its inception (Abu-Faraj, 2008b), as well as the current global explosion of 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. Furthermore, if the coordinated interaction among the key players within the field of Bioengineering/Biomedical Engineering, namely students, universities, hospitals, industries, professional societies and organizations, and governmental agencies and ministries, is enriched and solidified, then such diffusion is more viable.

The mapping of bioengineering/biomedical engineering education within the six continents is illustrated in Figures 3-a through 3-f, and is concurrently followed by a basic analysis pertaining to the academic distribution of the said field within each continent.

However, in order to better understand the illustrated distribution within each continent, a metric had to be formulated by dividing the number of population in a continent by the number of bioengineering/biomedical engineering programs offered within the same continent. Then, the smallest of the six obtained numbers was selected to normalize all values to a unitary value. The following factors were obtained: 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. It should be noted that the smaller the factor the higher is the outreach of bioengineering/biomedical engineering education per individual per continent.

Accordingly, upon examining Figure 3a for Africa, it is apparent from the extent of the white shading that this continent lags behind that of North America by a factor of 32.31:1.00. For example, 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.

World Population				
World Countries				
Total World Universities				
CONTINENT DATA	**AFRICA**	**ASIA**	**EUROPE**	**NORT AMER**
Continent Population	1007430000	4244615000	610708000	53961
Total Continent Countries	53	44	47	
Continent Countries w/ Universities	48	44	46	
Continent Population Offered Higher Education	1006566000	4244615000	610708000	53961
Continent Population Not Offered Higher Education	864000	0	0	
Number of Universities in Continent	793	4147	2204	
Number of People Per Single Continent University	1269314	1023539	277091	22
Number of Universities in Continent Offering Bioengineering/Biomedical Engineering	13	275	152	
Number of Countries in Continent Offering Bioengineering/Biomedical Engineering	7	23	29	
% of World Population in Continent	14.75%	62.15%	8.94%	7
% of Continent Population Not Offered Higher Education	0.09%	0.00%	0.00%	0
% of World Countries in Continent	27.46%	22.80%	24.35%	11
% of Total Continent Countries w/ Universities	90.57%	100.00%	97.87%	73
% of Total World Universities in Continent	7.59%	39.67%	21.08%	22
% of Universities in Continent Offering Bioengineering/ Biomedical Engineering	1.64%	6.63%	6.90%	9
% of Countries in Continent Offering Bioengineering/ Biomedical Engineering	13.21%	52.27%	61.70%	26

Table 4. 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).

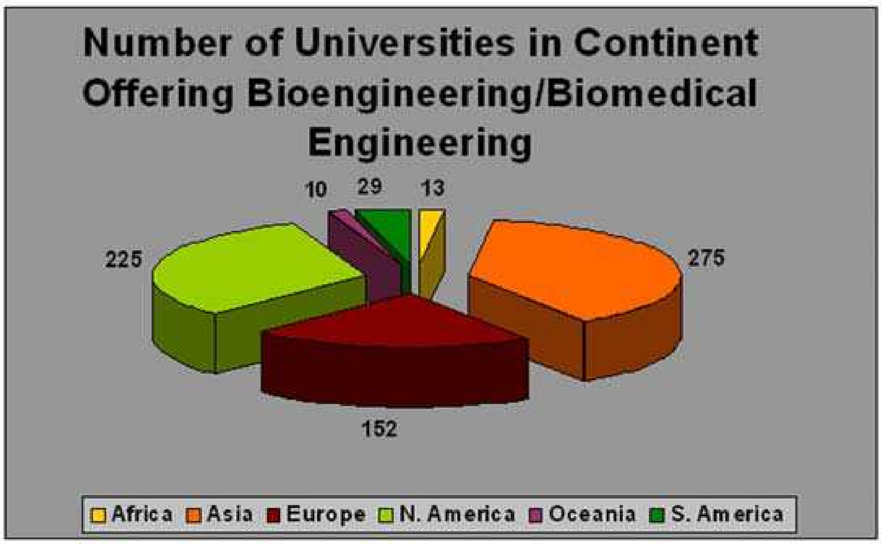
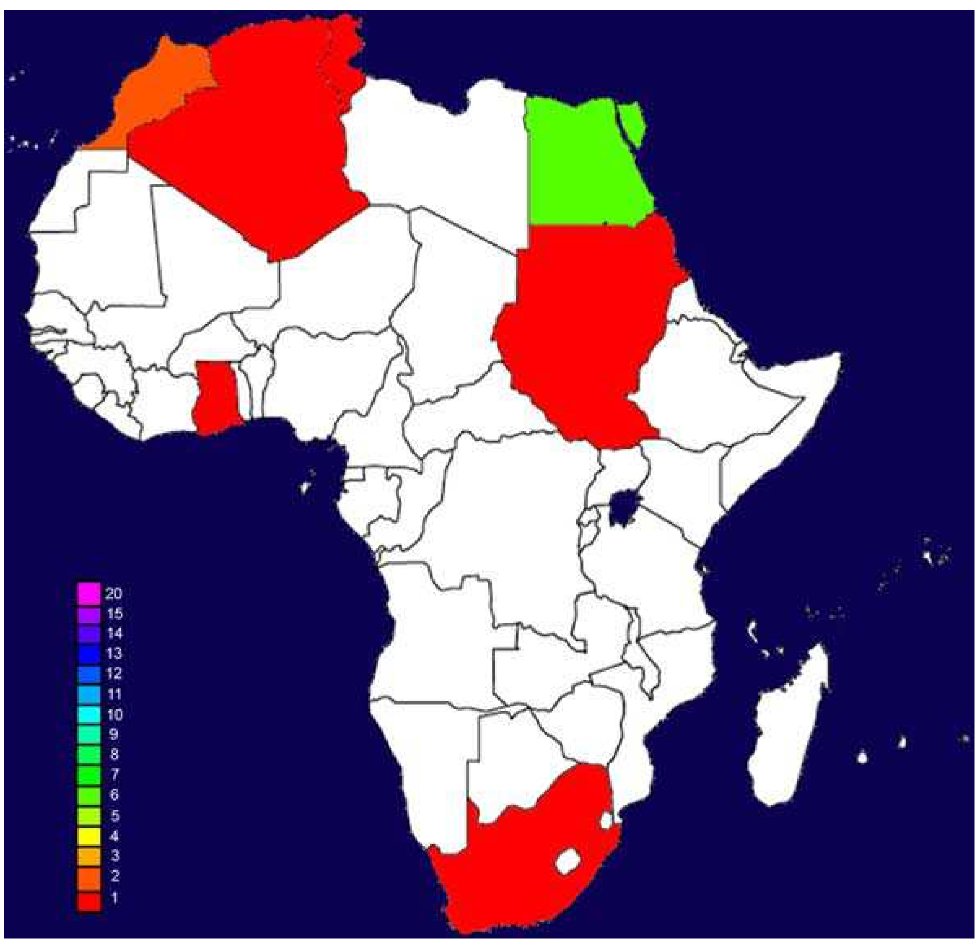
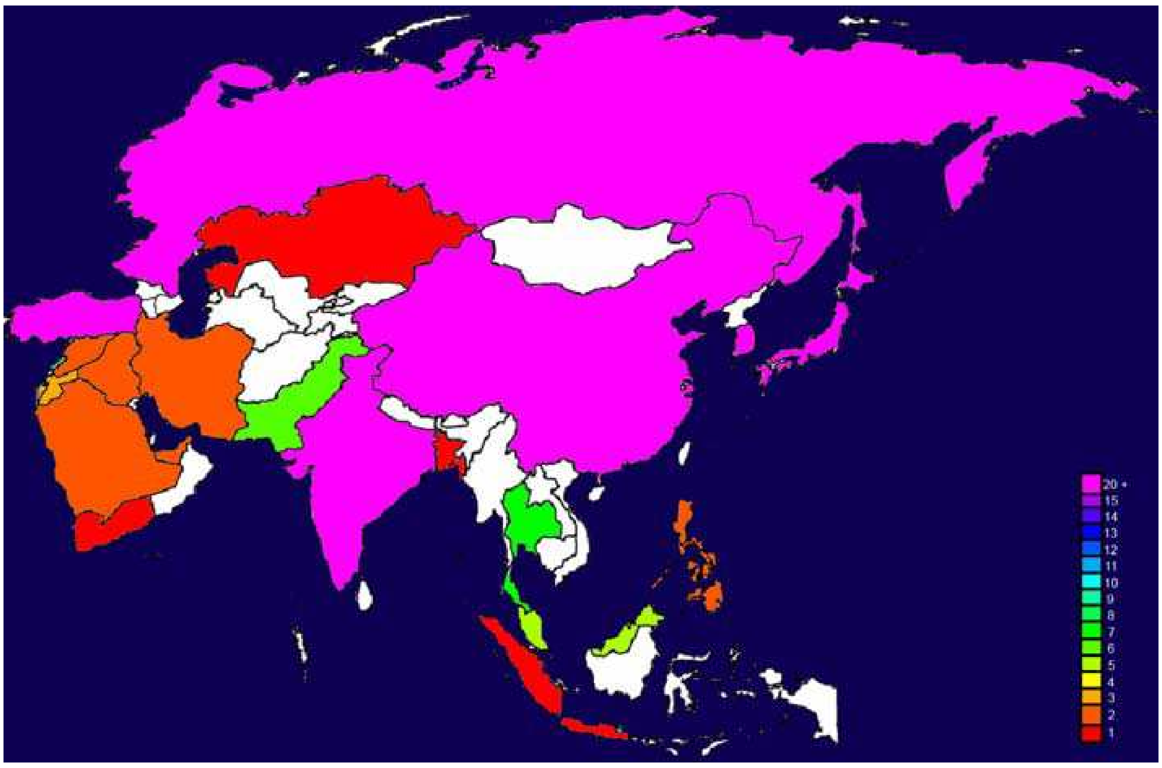


Fig. 2. A pie chart showing the number of universities in each continent offering bioengineering/biomedical engineering education.



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

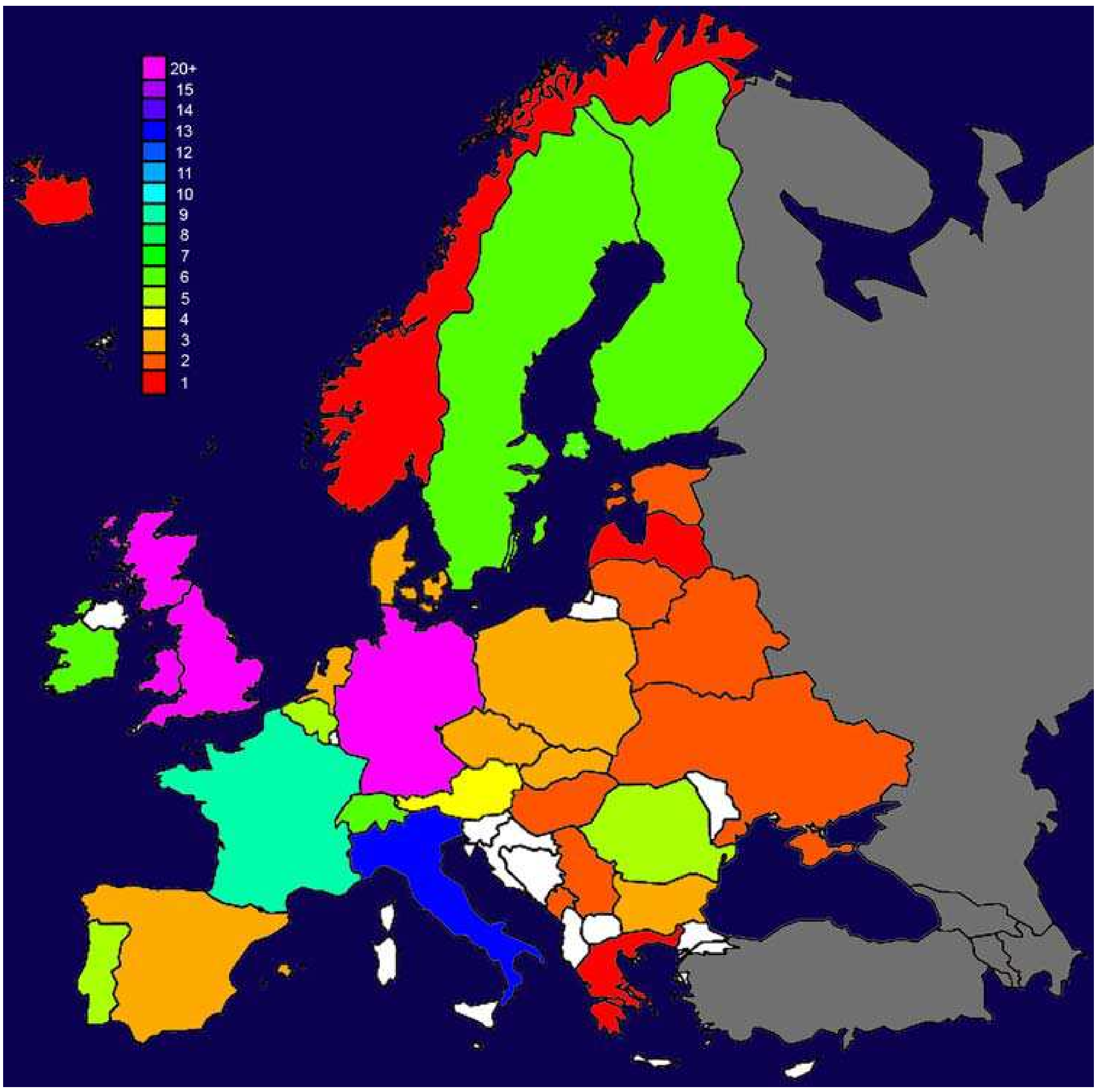
Fig. 3a. The mapping of bioengineering/biomedical engineering education in Africa. Note that the white shade indicates zero programs in a country.



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		

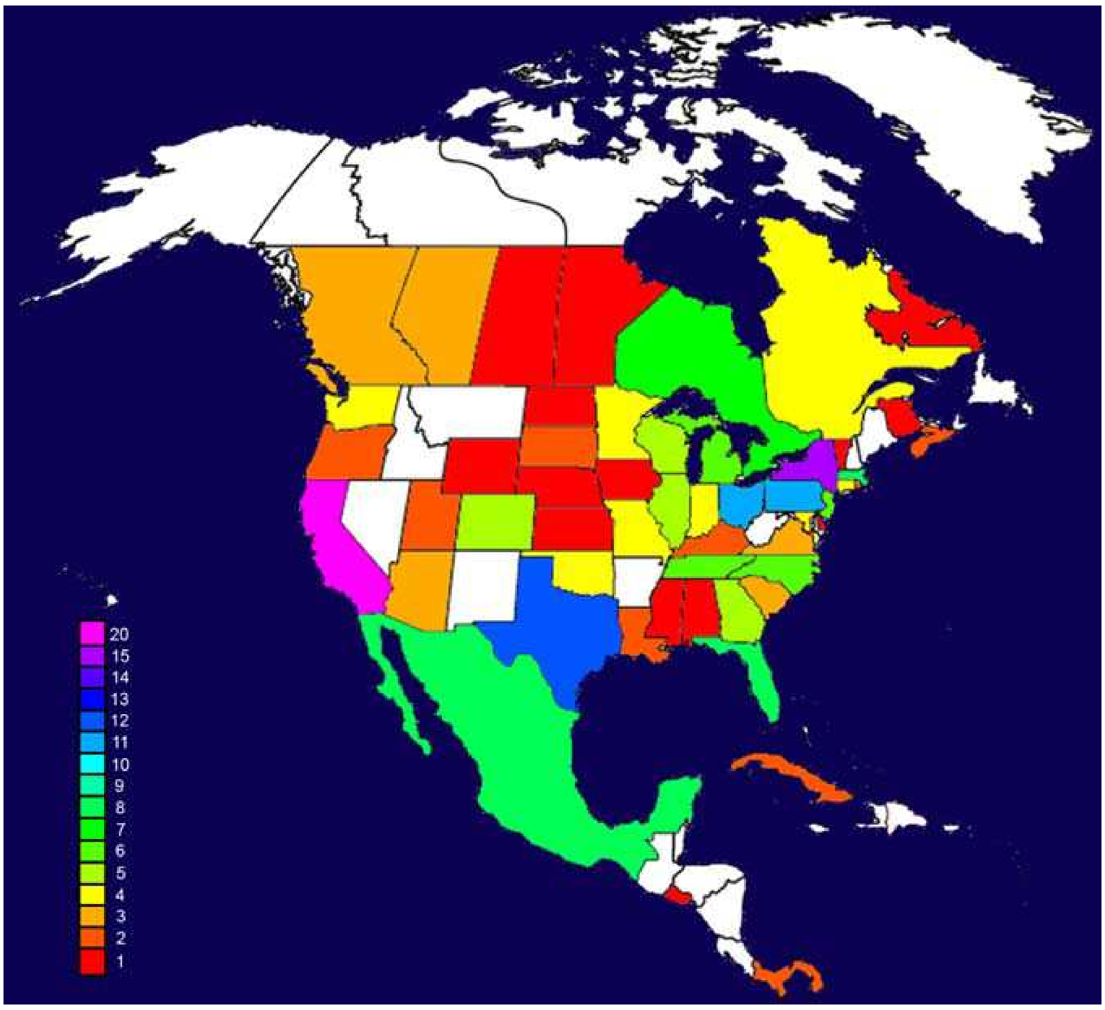
Fig. 3b. The mapping of bioengineering/biomedical engineering education in Asia.

With regard to Asia (Figure 3b), 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; i.e., 275 vs. 225. Of particular interest within this continent are the numbers obtained for China, Japan, India, Korea, Russian Federation, and Turkey. Europe (Figure 3c) is comparable with North America with a factor of 1.68:1.00; most prominently are the numbers of programs within the United Kingdom and Germany. It is important to note that there is 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. As for North America (Figure 3d), the U.S. presents a formidable number of 189 programs to be followed by the 23 programs found in Canada. Though small in population, Oceania (Figure 3e) is also comparable with North America with a factor of 1.42:1.00; yet, bioengineering/biomedical engineering education is restricted to Australia and New Zealand. Lastly, although South America (Figure 3f) lags behind North America with a factor of 5.59:1.00, yet it has 29 programs in the said field ensuring the coverage of 50% of the continent's countries.



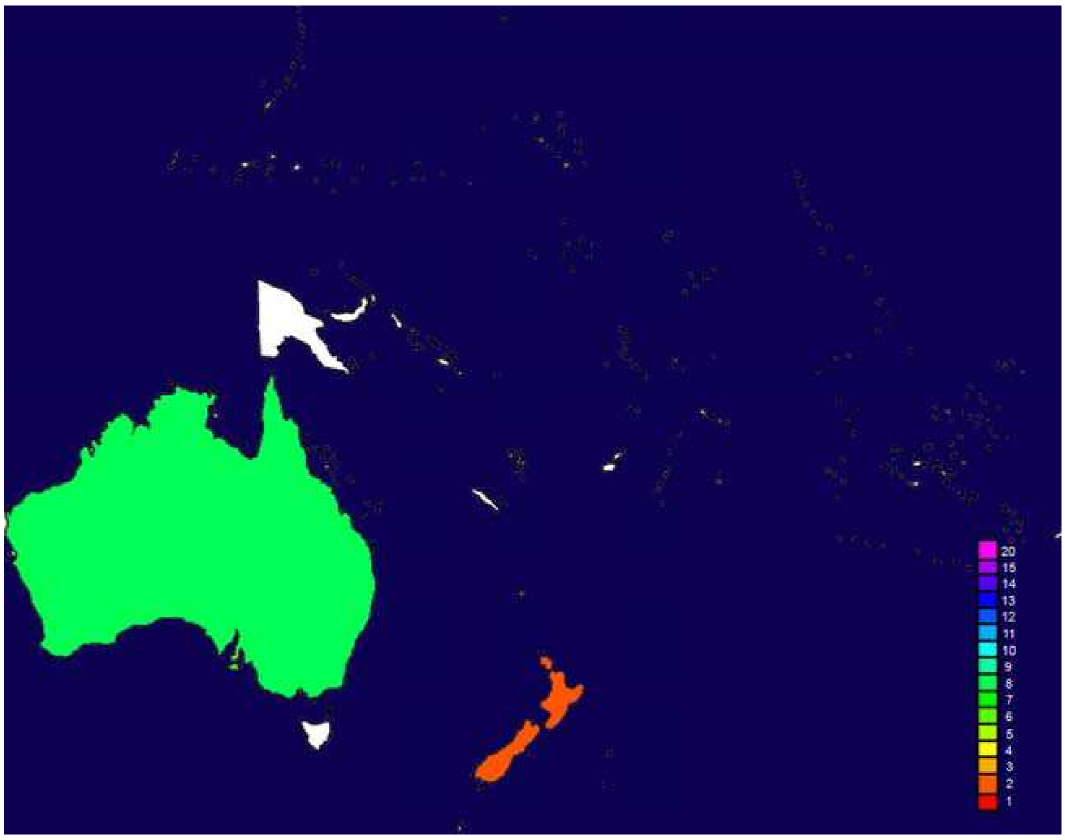
Austria	4	France	9	Lithuania	2	Spain	3
Belarus	2	Germany	23	Netherlands	3	Sweden	6
Belgium	5	Greece	2	Norway	1	Switzerland	6
Bulgaria	3	Hungary	2	Poland	3	Ukraine	2
Czech Republic	3	Iceland	1	Portugal	5	United Kingdom	26
Denmark	3	Ireland	6	Romania	5		
Estonia	2	Italy	13	Serbia	2		
Finland	6	Latvia	1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

Fig. 3c. The mapping of bioengineering/biomedical engineering education in Europe.



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

Fig. 3d. The mapping of bioengineering/biomedical engineering education in North America.



Australia 8 New Zealand 2

Fig. 3e. The mapping of Bioengineering/Biomedical Engineering education in Oceania.

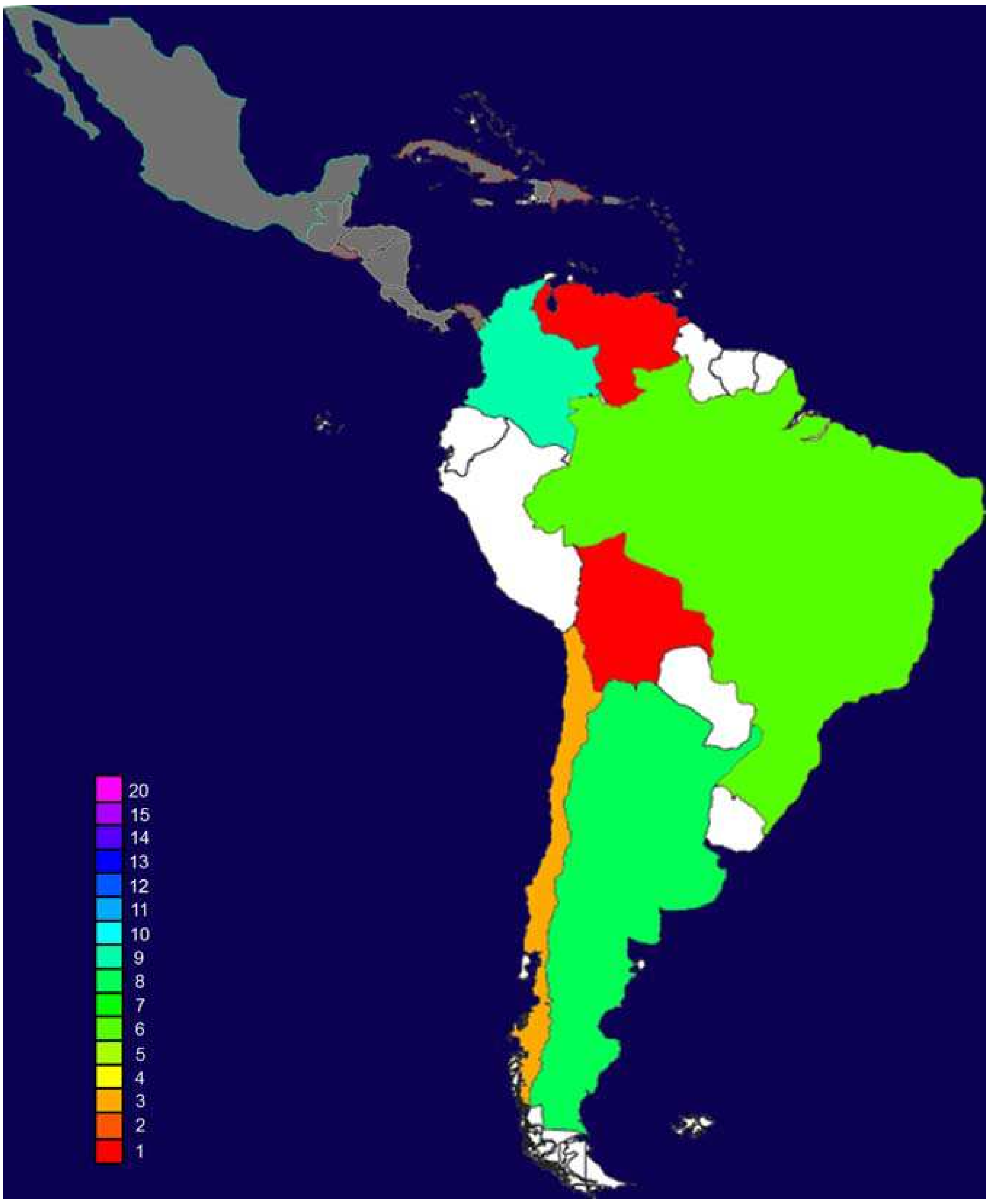
5. Conclusions

Project Alexander the Great revealed that bioengineering/biomedical engineering education is globally undergoing a healthy growth. There are currently 704 programs in bioengineering/biomedical engineering worldwide, offered in 6.73% of the world universities; two numbers that are worth constant monitoring as the world is witnessing a rapid perpetual change in this field.

The U.S. Department of Labor, Washington, DC, USA, reported that "the number of biomedical engineering jobs will increase by 31.4 percent through 2010 ... double the rate for all other jobs combined." Hence, the overall job growth in this field will by then average a 15.2 percent (Anonymous, 2007b).

This forecast for bioengineering/biomedical engineering jobs is reflected in Figure 4, which highlights the student enrollment in biomedical engineering within the United States in 1975-2003. A particular feature of this figure is the rapid surge in bioengineering/biomedical engineering enrollment that started in 1999.

Despite this overwhelming anticipated growth, employment indicators show that it is unlikely that this field will saturate any time soon.



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

Fig. 3f. The mapping of bioengineering/biomedical engineering education in South America.

It is worthwhile mentioning that the above forecast was made before the 2008 World Economic Crisis. Although, to date, no tangible signs have been visible as of the impact of this crisis on bioengineering/biomedical engineering education, yet this matter remains to be appraised.

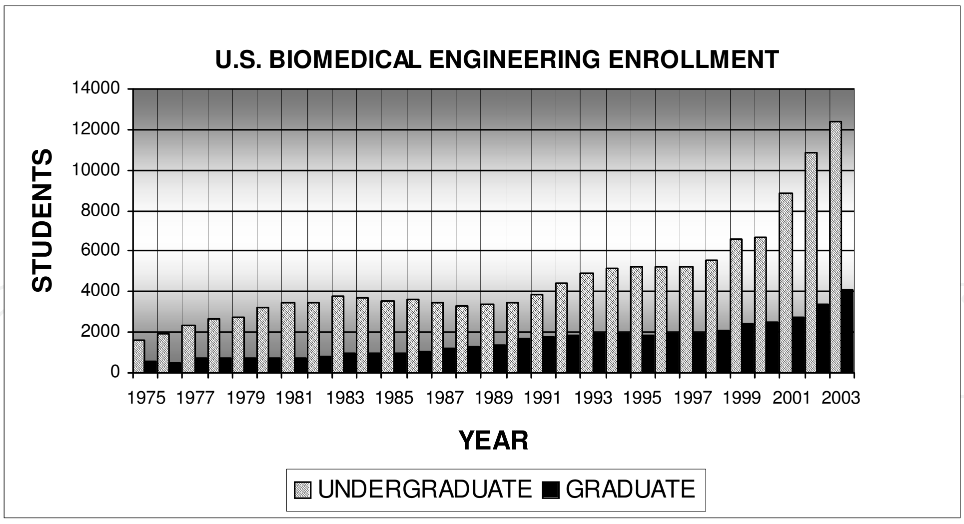


Fig. 4. Undergraduate and graduate student enrollment in biomedical engineering in the United States between 1975 and 2003. (Data was reproduced by digitization from the Whitaker Foundation website (Anonymous, 2006), and extended from Pilkington *et al.* (1989)).

To conclude, the relevance of Project Alexander the Great is multifold:

i. 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.
ii. The global networking of bioengineering/biomedical engineering academic and research programs.
iii. The promotion of first-class bioengineering/biomedical engineering education and the catalysis of global proliferation of this field.
iv. The erection of bridges among educational institutions, industry, and professional societies or organizations involved in bioengineering/biomedical engineering.
v. The catalysis in the establishment of framework agreements for cooperation among the identified academic institutions offering curricula in this field.

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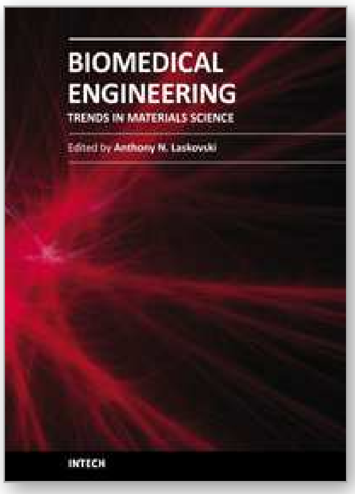

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Rapid technological developments in the last century have brought the field of biomedical engineering into a totally new realm. Breakthroughs in materials science, imaging, electronics and, more recently, the information age have improved our understanding of the human body. As a result, the field of biomedical engineering is thriving, with innovations that aim to improve the quality and reduce the cost of medical care. This book is the second in a series of three that will present recent trends in biomedical engineering, with a particular focus on materials science in biomedical engineering, including developments in alloys, nanomaterials and polymer technologies.

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No.65, Yan An Road (West), Shanghai, 200040, China

中国上海市延安西路65号上海国际贵都大饭店办公楼405单元

Phone: +86-21-62489820

Fax: +86-21-62489821