AMERICAN UNIVERSITY OF BEIRUT

FACULTY OF ENGINEERING AND ARCHITECTURE (FEA)
&
FACULTY OF MEDICINE (FM)

PROPOSAL FOR A MASTER’S DEGREE PROGRAM IN
BIOMEDICAL ENGINEERING

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– Walid Saad [Chemical Engineering, FEA]
– Darine Salam [Civil and Environmental Engineering, FEA]

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<tr>
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<tr>
<td>Date for initial proposal submission:</td>
<td>October 7, 2013</td>
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<tr>
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<td>November 14, 2013</td>
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<td>Date for revised version after feedback from FM:</td>
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PREAMBLE

The Faculty of Engineering and Architecture (FEA) and the Faculty of Medicine (FM) formed a joint FEA-FM Committee in January 2012 to work on a proposal for a new interdisciplinary Biomedical Engineering Program (BMEP) offering Master’s and PhD degrees in Biomedical Engineering. The BMEP is developed by capitalizing on existing faculty expertise, available laboratory facilities, and ongoing joint collaborations.

The BMEP aims at producing high caliber post graduate engineers to fulfill a regional need and to tackle health and medical challenges at the local and global levels by applying knowledge and research approaches from the biomedical and clinical sciences in conjunction with quantitative and design principles, methods, and tools from the engineering disciplines. The BMEP will strengthen interdisciplinary education and research at the American University of Beirut (AUB) while nurturing sustainable and scalable collaborations between FEA and FM.

The BMEP is developed in line with FEA vision to strengthen interdisciplinary educational and research collaborations, AUB Medical Center (AUBMC) 2020 vision in terms of research innovations, partnerships, and expansion, and the Provost’s initiatives to expand interdisciplinary research and education that focus on local and regional priorities.

Why Biomedical Engineering? Why at AUB? Why Now?

Biomedical Engineering is a core integrating discipline due to its key role in driving innovations, discoveries, and breakthroughs that are shaping the global health sector, improving the quality of life of people, and saving lives around the world.

AUB is the leading university in the Arab World with world-class faculties of engineering and medicine located on the same campus. Therefore, it is a natural move for these two established faculties to work hand-in-hand towards a new era of joint research and education collaborations founded on contemporary graduate academic programs. This initiative is at the center of the missions of both faculties.

- **FEA mission:** The Faculty of Engineering and Architecture at the American University of Beirut is a leading professional school in the Middle East. The FEA offers educational programs of the highest standards, promotes research and creative scholarly activities of its faculty and students, and provides services to the community at large, while addressing the needs of Lebanon and the region. The FEA undergoes continuous improvement to maintain a challenging and intellectually stimulating environment, and prepares its students to be life-long learners, innovators, and professionals capable of being leaders in their chosen careers, committed to personal integrity and civic responsibility.

- **FM mission:** The AUB Medical School and Medical Center will reassert their historic position as the premier medical school and finest tertiary care center in the Middle East, respectively; characterized by a revitalized hospital infrastructure, responsive patient services, outstanding clinical performance based on innovative clinical and information technologies and best trained faculty, centers of clinical and research excellence, and a
supportive network of associated clinics and hospitals locally and regionally. The medical school and center are committed to: educate and train the best physicians and biomedical research leaders to meet future health care needs in the region, advocating for the community’s well-being and access to care by providing quality patient care, cost effectiveness and patient satisfaction and performing premier clinical research and education.

The FEA was established in 1951 and is currently home to undergraduate and/or graduate programs in Chemical Engineering, Civil and Environmental Engineering, Electrical and Computer Engineering, Engineering Management, Industrial Engineering, Mechanical Engineering, Architecture, and Graphic Design. The FEA currently has over 80 full time faculty members, 2170 undergraduate students, 250 Master’s students, and 60 PhD students. FEA programs have been approved by and registered in the New York State Education Department (NYSED). Moreover, the FEA’s Bachelor of Engineering degrees in Civil Engineering, Computer and Communications Engineering, Electrical and Computer Engineering, and Mechanical Engineering are ABET accredited since October 2009.

The FM and the AUBMC have been providing services in the realms of medical education, training, and health care to their immediate constituencies in Lebanon and the Middle East since they were established in 1867. To date, the FM has graduated more than 4,225 physicians and there is a large postgraduate training program of over 280 residents in its various departments. The FM programs have been approved by and registered in the NYSED. Moreover, the FM and AUBMC have achieved the following accreditations: The Middle States Commission on Higher Education, The Joint Commission International (JCI) for Hospital Accreditation, Accreditation of AUBMC by the Lebanese Ministry of Public Health, Accreditation of the School of Nursing by the Commission on Collegiate Nursing Education (CCNE), Accreditation of the Nursing Services at AUBMC by the American Nurses Credentialing Center (ANCC), and The College of American Pathologists (CAP).

In the following, some facts and observations are listed that can serve as motivation, demand evidence, and/or success indicators for establishing a BMEP at AUB that offers both Master’s and PhD degrees in Biomedical Engineering.

**Potential FEA/FM Research Collaboration**

Based on an email survey of FEA faculty members in 2012, 24 faculty members (over 25% of the total number of faculty members in FEA) are either active or interested in conducting research in the field of biomedical engineering spanning a broad range of topics that include bioheat modeling, nanomaterials and drug delivery systems, health informatics, medical devices, neuroengineering, therapeutic ultrasound, biomedical imaging and image processing, physiological monitoring, computational genomics, computational modeling of biological systems, biomechanics, etc.

During the academic year 2012-13, the FM offered grant opportunities under three funding programs focused on interdisciplinary research projects between faculty members in the FM and colleagues from other departments across campus with budgets that ranged between
$20,000 and $100,000 per grant. In total 40 proposals were submitted of which 10 included PIs or Co-PIs from the FEA. This provides evidence of existing ongoing research interactions and collaborations among faculty members from both faculties.

**Potential Student Interest**

The student interest, though not easy to gauge, is perceived to be significant. There are already many existing elective courses offered in both the FEA and FM related to biomedical engineering and biomedical sciences, respectively. These courses are offered on a regular basis and are well attended by graduate students enrolled in the existing majors in both faculties. As an example, in spring term 2013, a visiting professor at the FEA gave a three-credit graduate-level special topics course titled “Tissue Engineering and Turning Discoveries into Clinical Products”; it was interesting to observe that 20 students registered in the course including six from Biomedical Sciences in the FM, nine from Mechanical Engineering, and five from Electrical and Computer Engineering. Students at the end of the course praised the interdisciplinary aspects of the course in terms of both content and class interactions. This is the type of interdisciplinary education that the BMEP will establish and nurture.

The FEA currently has over 250 students enrolled in various Master’s programs in engineering (Civil Engineering, Electrical and Computer Engineering, Engineering Management, Environmental and Water Resources Engineering, and Mechanical Engineering). Many of these students follow the thesis option and are supported by teaching and research assistantships. The FM currently has over 48 students enrolled in various Master’s programs in biomedical sciences (Biochemistry, Human Morphology, Microbiology and Immunology, Pharmacology and Therapeutics, and Physiology).

PhD programs were launched at the FEA in 2007. Currently there are around 60 students enrolled in four PhD programs that include Civil Engineering, Electrical and Computer Engineering, Environmental and Water Resources Engineering, and Mechanical Engineering.

The PhD program in Biomedical Sciences at FM was launched in the academic year 2012-13; 10 applications were received, five were shortlisted and three were accepted. In the academic year 2013-14, the number of applications significantly increased to 25 with 11 shortlisted and four accepted. Currently, there are seven PhD students in addition to 54 Master’s students enrolled in the Biomedical Sciences program. These facts from graduate programs in the FEA and FM demonstrate the potential high student interest in graduate level education at both faculties; in particular, the increase in the number of applications to the PhD program in Biomedical Sciences in only two years is a significant indicator of the potential interest in advanced research addressing health and medical related challenges.

**Potential Faculty Recruitment Interest**

The FEA has opened two positions related to biomedical engineering during the academic year 2012-13. More than 30 applications were received mostly from doctoral holders working in the USA. A search committee was set and went through a selection process that resulted in short listing and inviting to interviews five applicants. As a result, two distinguished applicants were
recommended and offered positions to join the FEA during the academic year 2013-14; one has already accepted the offer and is expected to join beginning of 2014, whereas the second one requested an extension before taking a final decision and, thus, is still pending.

These facts reflect on one hand the determination of the Deans to support the new programs via new faculty lines even when the proposals were still in preparation, and on the other hand high interest from established PhD holders to join AUB and contribute to teaching and research in Biomedical Engineering.

**Potential Need and Competition at the Local and Regional Levels**

The table below presents a summary of existing university programs related to Biomedical Engineering in Lebanon. It can be seen that there are currently no universities in Lebanon that offer a PhD degree in Biomedical Engineering.

Most existing programs are at the undergraduate (BS or BE) level and focused on specific emphasis areas related to Biomedical Engineering. Master’s degree programs are limited to two universities, namely, Balamand University which offers an MS degree in Electrical Engineering with option in Biomedical Sciences, and the Holy Spirit University of Kaslik (USEK) which offers a specialized Master’s degree in Biomedical Engineering encompassing three tracks in biomechanics, bioinformatics, and biomedical instrumentation. A professional Master’s degree in Biomedical Physics is offered at the Lebanese University (LU) and focuses on quality control in hospitals, medical radiophysics, and medical/industrial applications.

<table>
<thead>
<tr>
<th>University</th>
<th>Degree</th>
<th>Faculty/Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lebanese University (LU)</td>
<td>Professional Master’s in Biomedical Physics with focus on either quality control or medical radiophysics</td>
<td>Faculty of Sciences, Physics Department</td>
</tr>
<tr>
<td></td>
<td>Professional Master’s in Medical and Industrial Applications</td>
<td></td>
</tr>
<tr>
<td>Saint Joseph University (USJ)</td>
<td>Diploma in Biomedical Engineering with focus on design and manufacturing of medical devices, marketing and maintenance of medical devices, signal and medical information processing, telemedicine, and hospital management.</td>
<td>Higher Institute for Engineering in Beirut</td>
</tr>
<tr>
<td>Balamand University</td>
<td>MS in Electrical Engineering with option in Biomedical Engineering</td>
<td>Faculty of Engineering, Department of Electrical Engineering</td>
</tr>
<tr>
<td>Holy Spirit University of Kaslik</td>
<td>BS in Engineering Sciences with option in Biomedical Engineering</td>
<td>Faculty of Engineering, Department of Biomedical Engineering</td>
</tr>
<tr>
<td>(USEK)</td>
<td>MS in Biomedical Engineering with focus on biomechanics, bioinformatics, or biomedical instrumentation</td>
<td></td>
</tr>
<tr>
<td>Islamic University of Lebanon</td>
<td>BE in Biomedical Engineering</td>
<td>Faculty of Engineering</td>
</tr>
<tr>
<td>(IUL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>American University of Science and Technology (AUST)</td>
<td>BS in Biomedical Engineering</td>
<td>Faculty of Engineering and Computer Science, Department of Biomedical Engineering</td>
</tr>
<tr>
<td></td>
<td>MS in Biomedical Engineering</td>
<td></td>
</tr>
<tr>
<td>Al-Manar University of Tripoli (MUT)</td>
<td>BS/BE in Biomedical Engineering</td>
<td>Faculty of Engineering and Information Technology</td>
</tr>
<tr>
<td>Lebanese International University</td>
<td>BS in Electronic Engineering with emphasis in biomedical engineering</td>
<td>School of Engineering, Department of Electronics</td>
</tr>
<tr>
<td>(LIU)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Graduate level programs in Biomedical Engineering are not widespread in the Arab World, with few exceptions. For example, King Abdul Aziz University (KAAU) in KSA offers Master’s degree in Biomedical Engineering with focus on bioinstrumentation, medical imaging, medical informatics, and clinical engineering; American University in Cairo (AUC) offers intensive courses related to biosafety in addition to quality assurance and quality control in pharmaceutical and biomedical industries. At the undergraduate level, there are several BS programs in Biomedical Engineering, e.g., at Jordan University of Science and Technology (JUST) in Jordan, Cairo University in Egypt, and Khalifa University in UAE.

**Potential Market Demand**

Graduates with a PhD degree in Biomedical Engineering typically pursue a career either in industry or academia.

On the local and regional levels, several academic institutions offer programs in Biomedical Engineering and Biomedical Sciences. These institutions present academic employment opportunities for PhD graduates from the graduate Biomedical Engineering program at AUB.

On the local and regional levels, no data were found on the number of PhD graduates in Biomedical Engineering. Since no university in Lebanon offered a PhD program in this field, and very few offer ones in the region, the number of graduates with a PhD degree from local and regional institutions is expected to be low. This represents an opportunity for AUB to be a pioneer in the region through introducing new graduate degrees in Biomedical Engineering.

In the case of the USA, where statistical data were found, the employment opportunities are met with a relatively significant number of graduates. According to the National Center for Education Statistics (NCES), for the year 2009/2010, the following degrees in Biomedical Engineering were conferred by degree-granting institutions:

<table>
<thead>
<tr>
<th>Bachelor’s Degrees</th>
<th>Master’s Degrees</th>
<th>PhD Degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,775</td>
<td>1,380</td>
<td>749</td>
</tr>
</tbody>
</table>


On the local and regional levels, the potential industry demand for PhDs in Biomedical Engineering would probably lie with major multinational biomedical companies represented in the region, such as Medtronic, Karl Storz, and General Electric. Other potential employers for PhD graduates include hospitals and associated centers of excellence, e.g., the newly established centers of excellence at AUBMC [http://www.aubmc.org/Documents/2020.PDF](http://www.aubmc.org/Documents/2020.PDF). Additionally, the BMEP at AUB can lead to discoveries and patents that can spin off local startups and, thus, contribute to building a biomedical engineering industry in Lebanon.

On the international level, employment data were found for the USA. The Bureau of Labor Statistics report for occupational employment and wages of May 2011 pertaining to Biomedical Engineering (all degree levels) reveals the following facts:
<table>
<thead>
<tr>
<th>Description</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA total employment</td>
<td>16,590 (including 1,410 in colleges, universities, and professional schools)</td>
</tr>
<tr>
<td>Mean annual wage</td>
<td>$88,360</td>
</tr>
<tr>
<td>Percentile wage</td>
<td>$51,380 (10%)</td>
</tr>
<tr>
<td></td>
<td>$134,150 (90%)</td>
</tr>
<tr>
<td>Industries with the highest level of employment in this occupation</td>
<td>Medical equipment and supplies manufacturing: 3,830</td>
</tr>
<tr>
<td></td>
<td>Scientific research and development services: 3,110</td>
</tr>
<tr>
<td></td>
<td>Pharmaceutical and medicine manufacturing: 2,640</td>
</tr>
<tr>
<td></td>
<td>Colleges, universities, and professional schools: 1,410</td>
</tr>
</tbody>
</table>

**Source:** [http://www.bls.gov/oes/current/oes172031.htm#%281%29](http://www.bls.gov/oes/current/oes172031.htm#%281%29)

PhD programs were launched at the FEA in 2007. Currently there are around 60 students enrolled in four PhD programs that include Civil Engineering, Electrical and Computer Engineering, Environmental and Water Resources Engineering, and Mechanical Engineering. Between 2007 and 2013, more than 18 PhD students have graduated and most of them were able to get attractive post-graduation opportunities. For example, two got full-time assistant professor positions at local universities (NDU, BAU) in Lebanon, one is working as a research scientist in a research center (QMIC) in Qatar, one is working in a European research center in Beirut (Beirut Research and Innovation Center), one is a post-doctoral fellow in Princeton, one is a post-doctoral fellow in KAUST, two are post-doctoral fellows in AUB, and few are teaching on a part-time basis at different local universities (AUB, NDU, LAU, AUST, etc.).
1. PROGRAM DATA

- Program title: Biomedical Engineering
- Degree: Master’s of Engineering (ME)
- HEGIS code (New York State Taxonomy of Academic Programs): 0905

2. PURPOSE, GOALS, AND OBJECTIVES

Mission Statement

The Biomedical Engineering Program (BMEP) at the American University of Beirut is an interdisciplinary graduate program that provides excellent education and promotes innovative research enabling students to apply knowledge and approaches from the biomedical and clinical sciences in conjunction with design and quantitative principles, methods, and tools from the engineering disciplines to address human health related challenges of high relevance to Lebanon, the Middle East, and beyond. The program prepares its students to be leaders in their chosen areas of specialization committed to lifelong learning, critical thinking, and intellectual honesty.

Goals

The central goals of the BMEP are to facilitate the development of students into independent researchers, specialized engineers, and/or qualified educators by providing well-rounded interdisciplinary education and to foster research creativity to positively impact the health and medical sectors in Lebanon and the region.

These goals will be achieved via:

- Offering a rich curriculum designed jointly by FEA/FM that emphasizes strong interdisciplinary education and fosters solid research ties between FEA and FM.
- Capitalizing on existing FEA/FM faculty expertise and laboratory facilities, available AUBMC human and capital resources, and ongoing FEA/FM research collaborations.
- Creating interdisciplinary research teams composed of graduate students, laboratory engineers and scientists, postdoctoral fellows, clinical doctors, and faculty members. These research teams can potentially evolve towards interdisciplinary research centers.
- Attracting large-scale research funding and developing collaboration agreements with established international universities, research laboratories, and companies.

The BMEP is in line with the mission statements of AUB, FEA, and FM in terms of providing excellence in education, advancing knowledge through research, and serving the people of the Middle East and beyond. It comes at a time where AUB is impinging on major initiatives to fuel interdisciplinary education and research across the University.

The BMEP will be supported substantially by existing resources at the FEA and FM in terms of faculty member expertise, courses, laboratory facilities, etc. Moreover, additional faculty lines
and funding will be allocated at both faculties, as needed, in order to fill any gaps and guarantee smooth launching and successful implementation.

The BMEP will offer both Master’s and PhD degrees in Biomedical Engineering. This proposal is focused on the Master’s academic program which will be denoted in the sequel as the Master’s Program in Biomedical Engineering (MBME).

**MBME Educational Objectives**

The MBME educational objectives are to graduate Master’s students able to:
- Achieve their goals in post-graduate studies and industry employment in fields related to Biomedical Engineering
- Advance in their careers through innovation, leadership, life-long learning, and integrity

**MBME Student Learning Outcomes**

At the time of graduation, the following student learning outcomes will be achieved:
- Utilize interdisciplinary knowledge from various fields to work on projects and conduct research in biomedical engineering
- Communicate project/research findings, in both oral and written formats, through presentations and technical reports
- Demonstrate basic knowledge of fundamental principles in various subareas of biomedical engineering
- Demonstrate in-depth knowledge in a specific subarea in biomedical engineering
- Appreciate the complexity and the importance of emerging new scientific findings in biomedical engineering
- Demonstrate understanding of the importance of teamwork, life-long learning, and ethical responsibility

**Research Focus Areas and Relation to Other Programs**

The DBME will be initially composed of three research focus areas that have been carefully selected based on existing expertise, available resources, and potential impact. These are:
- **Biomedical Systems**: This focus area includes research directions such as devices, instrumentation, biomechanics, biomaterials, drug delivery systems, and tissue engineering.
- **Biomedical Cybernetics**: This focus area includes research directions such as biomedical and health informatics, computational biology, biomedical signal/image processing, and biomedical systems engineering.
- **Cardiovascular and Pulmonary Engineering**: This focus area includes research directions such as fluid mechanics, modeling, simulation, imaging, devices, and implants related to both human cardiovascular and pulmonary systems.
The MBME will complement existing related programs at AUB and, thus, will be a valuable addition to AUB’s graduate academic portfolio. The following list includes graduate programs existing at AUB that are related to the proposed MBME:

- **Interfaculty Graduate Neuroscience Program (IGNP) [HEGIS: 0425]:** MS degree focused on the study of the nervous system including both clinical (neurology, neurosurgery, neuropathology, psychiatry, etc.) and basic (neuroanatomy, neurophysiology, neurochemistry, neuropharmacology, etc.) disciplines. The program is housed in the FM with participating faculty primarily from the Physiology and Human Morphology Departments.

- **Graduate Program in Computational Science (GPCS) [HEGIS: 0799, 1799]:** MS degree focused on the utilization of mathematical modeling and computing as tools in solving application area problems in science, engineering, finance, economics, health, and medical sciences. The program is housed in the Faculty of Arts and Sciences (FAS) with primary role from the Computer Science and Mathematics Departments.

- **Doctoral Program in Biomedical Sciences (DBMS) [HEGIS: 0499]:** PhD degree focused on research and teaching in molecular and cellular medicine including seven disciplines in Biochemistry and Molecular Genetics, Cell Biology of Cancer, Microbiology and Immunology, Neurosciences, Nutrition, Pharmacology and Toxicology, and Physiology. The program is housed in the FM with primary role from the Biomedical Sciences Departments.

- **Undergraduate Minor in Biomedical Engineering [HEGIS: 0905]:** Minor offered by the FEA to undergraduate students in Engineering, Sciences, and others. Students are required to take 18 credits divided mainly between the Department of Electrical and Computer Engineering and Department of Biology.

- In addition, the MBME will be supported by various existing graduate programs in Engineering and Sciences. These include the following: ME and/or PhD programs in Chemical Engineering [HEGIS: 0906], Civil and Environmental Engineering [HEGIS: 0908], Electrical and Computer Engineering [HEGIS: 0909], and Mechanical Engineering [HEGIS: 0910]; MD degree in Medicine [HEGIS: 1206] and PhD degree in Cell and Molecular Biology [HEGIS: 0417]; MS degrees in Biochemistry [HEGIS: 0414], Biology [HEGIS: 0401], Chemistry [HEGIS: 1950], Computer Science [HEGIS: 0701], Human Morphology [HEGIS: 0499], Microbiology and Immunology [HEGIS: 0411], Neuroscience [HEGIS: 0425], Nutrition [HEGIS: 0424], Pharmacology and Therapeutics [HEGIS: 0410], Physics [HEGIS: 1902], and Physiology [HEGIS: 0410].
3. ACADEMIC GOVERNANCE

Governance Structure
The BMEP will be housed in the FEA and administered by both FEA and FM via a Joint Program Coordinating Committee (JPCC). The JPCC will be composed of six faculty members that include: program coordinator (PC) from FEA, co-program coordinator (co-PC) from FM, two members from FEA, and two members from FM. All members of the JPCC will be appointed in joint consultation between the Deans of FEA and FM. Moreover, the degrees of the graduating students will be voted on in both faculties and signed by both Deans. The following is a schematic that represents the general governance structure:

Oversight of the BMEP will occur at three different levels:
- **Program level:** The PC in collaboration with the co-PC, and in consultation with the JPCC, will manage the program’s day-to-day operation, curriculum issues, student admissions, student advising, budgeting and facilities, publicity, faculty recruitment, and curriculum assessment. The BMEP academic and administrative responsibilities of the PC will be governed based on AUB's guidelines for departmental chairpersons. Moreover, the JPCC will be responsible for program strategic planning, periodic assessment and evaluation, in addition to improvement and expansion plans.
- **Faculty level:** The JPCC will submit recommendations to either the FEA Graduate Committee, FM Graduate Committee or both for approval in line with the bylaws of these committees. For example, curriculum changes related to engineering courses need to be approved by the FEA Graduate Committee and the outcomes need to be shared with the
FM Graduate Committee, and vice versa. On the other hand, major changes such as number of credits or addition of a new focus area to the curriculum need to be approved by graduate committees at both faculties.

- **University level**: Certain recommendations of the Faculty Graduate Committees require the approval of the University Board of Graduate Studies in line with the existing bylaws; these cover normally major changes or modifications to the curriculum. Moreover, the JPCC will coordinate with the University Graduate Council on issues related to students’ admissions, progress, and petitions.

- **Professional level**: An External Advisory Board for the BMEP will be formed from local, regional, and international leaders in the biomedical industry and academia to align the program with emerging trends, identify market needs, foster collaborations, and help provide opportunities for graduating students.

**Student Admission Requirements**

The application procedures and admission requirements to the MBME will follow AUB Graduate Studies Policies and Procedures as documented in the Graduate Catalogue (see pp. 39-43 in Graduate Catalogue 2013-14). The program accepts applicants holding Bachelor’s Degree (BE/BA) with backgrounds from relevant fields of study including engineering, sciences, health professions, etc. Due to the interdisciplinary nature of the program’s curriculum, remedial courses may be needed for students on a case-by-case basis as discussed in Section 7 on Curriculum Design.

Acceptance of applicants into the MBME is determined by their academic performance as well as an assessment of readiness and potential to succeed as judged by interviews by selected faculty members, a written statement, letters of recommendation, and other means of assessment such as publications and industrial experience. The students’ admission process will be managed by the JPCC.

The general course, residence, thesis, and graduation requirements for the MBME will follow AUB’s guidelines as documented in the Graduate Catalogue (see pp. 55-60 in Graduate Catalogue 2013-14). Graduation requirements include course work, thesis proposal submission, comprehensive exam, thesis submission, and thesis defense. For specific degree requirements, check Section 7 on Curriculum Design.

**Faculty Workload and Promotion**

The introduction of the BMEP is not expected to lead to an increase in the workload of existing faculty members. In terms of teaching, the program relies to a large extent on existing courses at both FEA and FM; the teaching load of existing faculty members will not be impacted by the introduction of the program.

Moreover, new faculty lines will be added at the FEA and FM, as needed, to support the program in terms of teaching and research. In the FEA, new faculty members will be allocated temporarily to the existing engineering departments depending on their backgrounds and
areas of expertise, as long as there is no separate department or entity of Biomedical Engineering; these faculty members will have regular loads in line with FEA guidelines, will be primarily serving the BMEP in terms of service duties and graduate-level teaching as much as needed, and will be helping their temporary home departments in terms of undergraduate teaching.

In terms of mentorship and supervision, although demanding with new responsibilities, it is intellectually satisfying as it will allow faculty members to expand their research groups to include dedicated doctoral students addressing major research problems over a typical period of four to five years. Moreover, these efforts will be taken into account as part of annual evaluation of faculty members for the purpose of merit increase or promotion.

Criteria for promotion from assistant professor to associate professor and from associate professor to full professor are based upon achievements of excellence in scholarship, teaching and service, with higher weight towards scholarship activities measured by research productivity (quality of peer-reviewed publications, research funding, research awards, etc.). Thus, faculty members engaged in mentoring graduate students will benefit by enhancing the scale of their research activities which in turn leads to increasing their scientific productivity in terms of publications and funding. It is worth noting that tenure has been suspended at AUB in 1985. Currently, most faculty members have contracts between three and seven years. Moreover, a special task force appointed by the President is currently working on developing a proposal to reinstate tenure at AUB.
4. FINANCIAL RESOURCES

The table below presents a tentative cost-revenue analysis for the BMEP over duration of 10 years. This includes costs and revenues for both degrees Master’s and PhD, since the two programs are inter-dependent and planned to be initiated simultaneously. Data related to students’ projected enrollment is based on the details presented in Section 8 on Students. Data related to new faculty lines is based on details presented in Section 6 on Faculty.

<table>
<thead>
<tr>
<th>#</th>
<th>Academic Year</th>
<th>Expenditures Description</th>
<th>Itemized Cost ($)</th>
<th>Annual Cost ($)</th>
<th>Annual Tuition Revenue ($)</th>
<th>Annual Balance ($)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>2014-15</td>
<td>Capital Expenditure</td>
<td>1 150,000</td>
<td>280,000</td>
<td>74,088</td>
<td>-205,912</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operational Budget</td>
<td>1 40,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faculty Lines</td>
<td>2*0.5 90,000</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2015-16</td>
<td>Capital Expenditure</td>
<td>1 100,000</td>
<td>267,500</td>
<td>148,176</td>
<td>-119,324</td>
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<tr>
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<td>Operational Budget</td>
<td>1 40,000</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Faculty Lines</td>
<td>3*0.5 127,500</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>2016-17</td>
<td>Capital Expenditure</td>
<td>1 100,000</td>
<td>305,000</td>
<td>169,344</td>
<td>-135,656</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operational Budget</td>
<td>1 40,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faculty Lines</td>
<td>4*0.5 165,000</td>
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<td></td>
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<tr>
<td>4</td>
<td>2017-18</td>
<td>Operational Budget</td>
<td>1 40,000</td>
<td>205,000</td>
<td>190,512</td>
<td>-14,488</td>
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<td>Faculty Lines</td>
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<tr>
<td>5</td>
<td>2018-19</td>
<td>Operational Budget</td>
<td>1 40,000</td>
<td>205,000</td>
<td>211,680</td>
<td>6,680</td>
</tr>
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<td></td>
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<td>Faculty Lines</td>
<td>4*0.5 165,000</td>
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<td>6</td>
<td>2019-20</td>
<td>Operational Budget</td>
<td>1 40,000</td>
<td>205,000</td>
<td>211,680</td>
<td>6,680</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faculty Lines</td>
<td>4*0.5 165,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2020-21</td>
<td>Operational Budget</td>
<td>1 40,000</td>
<td>205,000</td>
<td>211,680</td>
<td>6,680</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faculty Lines</td>
<td>4*0.5 165,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2021-22</td>
<td>Operational Budget</td>
<td>1 40,000</td>
<td>205,000</td>
<td>211,680</td>
<td>6,680</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faculty Lines</td>
<td>4*0.5 165,000</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td><strong>Totals</strong></td>
<td></td>
<td><strong>$1,877,500</strong></td>
<td><strong>$1,422,840</strong></td>
<td></td>
<td><strong>-444,660</strong></td>
</tr>
</tbody>
</table>

Assumptions and Notes:

- Faculty lines included in the table correspond to new hires in the FEA. New faculty lines and capital expenditures from the FM are not taken into account since they are already planned as part of the existing Biomedical Sciences graduate programs. More details are included in Section 6 on Faculty.

- Faculty lines in the table are allocated as follows: 2014-15 one assistant professor and one associate professor; 2015-16 two assistant professors and one associate professor; 2016-17 and beyond three assistant professors and one associate professor. Total number of planned new faculty lines in the FEA is four.

- New faculty members are assumed to spend on average around half of their teaching load on the graduate Biomedical Engineering program and, thus, will be also involved in teaching activities within the existing undergraduate programs in the FEA. Therefore, only 50% of their salaries are included in the table. As an example, the faculty lines total cost in 2014-15 is calculated to be $90,000 as follows: $180,000 = $75,000 per
assistant professor with benefits + $105,000 per associate professor with benefits; 50% leads to the allocation of an annual expenditure of 90,000$.

- It is important to note that the teaching of undergraduate courses by new faculty members will lead to revenue generation; most undergraduate engineering courses typically have more than 30 enrolled students. This revenue is not included in the table since it is not feasible to quantify accurately.

- The capital expenditure budget aims at covering start-up funds for new faculty members including any needed research equipment and initial graduate student support. New faculty members will also utilize existing labs and equipment available on campus, as applicable. Allocation of any needed new lab space needs to be studied and approved on a case by case basis, and should not impact the existing lab allocations in the FEA.

- The annual operational budget aims at covering program administrative and operational annual costs. This budget will be added on top of the total FEA operational budgets allocated to the existing departments and, thus, should not impact the annual budget allocations of the departments.

- The tuition revenues assume 2 PhD and 5 Master’s enrolled per year, each student takes on average 12 credits/year, PhD student spends average 5 years and Master’s student average 2 years, steady state in year 5 with 20 students (10 PhD and 10 Master’s), credit cost 882$/credit. More details are included in Section 8 on Students.

- It is important to note that most graduate students are expected to cover their tuition via teaching assistantships, scholarship programs, research grants, and support from the University. Typically, only master’s students on the non-thesis track have to pay tuition.

- Inflation rates are ignored for both costs and revenues in the table.
5. FACILITIES, EQUIPMENT, AND LIBRARY

Computer Facilities
Graduate students have access to a wide range of computer facilities across campus distributed among graduate students office rooms, research laboratories, common computer laboratories, personal laptops, and mobile devices. For example, FEA computer and graduate student laboratories house more than 200 computers distributed within the different engineering buildings.

AUBnet provides a state-of-the-art wired and wireless network infrastructure ensuring high speed, secure, reliable, and widespread access for AUB users across the entire campus and hospital. AUB students can connect to AUBnet from public computer laboratories or personal laptops and mobile devices that access the campus-wide wireless network. Computer laboratories also offer a variety of other resources to students, such as printers, scanners, and secure network storage for personal data. Students may also request access to servers hosting specialized applications and software tools.

Classrooms
Students will utilize existing classrooms and teaching lab facilities on campus.

- For engineering courses, the classrooms are mainly located in the Bechtel Engineering Building. The classrooms have different sizes and are adequate to host a relatively large number of students. All classrooms are equipped with LCD projectors and projection screens in addition to wireless internet connectivity. The teaching laboratories are distributed across various engineering buildings including Raymond Ghosn Building (RGB), CCC Scientific Research Building (SRB), and the newly established Irani/Oxy Engineering Complex (IOEC).
- For biomedical sciences courses, the classrooms are mainly located in the Diana Tamari Sabbag (DTS) Building. The classrooms have different sizes and are adequate to host a relatively large number of students. All classrooms are equipped with LCD projectors and projection screens in addition to wireless internet connectivity. The DTS building is currently undergoing major renovations to upgrade all teaching as well as research facilities. The teaching laboratories are also distributed across various AUBMC buildings.
- For other courses such as sciences or external electives, classes are held in classrooms scattered across different buildings on campus.

Libraries [Statistics taken from Graduate Catalogue 2013-14, pp. 31-32]
AUB libraries consist of the following: Jafet Memorial Library (the central library of the AUB campus), the Engineering and Architecture Library, Saab Memorial Medical Library (SML), and the Science and Agriculture Library, with its annex AREC (Farm) Library. The libraries have a long history in Lebanon and in the region which is reflected in the rich collections that they own. The collections consist of 386,759 books in 464,708 volumes and 6,828 print periodicals in
186,355 volumes. The libraries also own 218,293 electronic books and provide access to 87,701 electronic periodicals and 800 journals on microfilm. The libraries currently subscribe to 5,000 electronic periodicals, 780 print periodicals, and 252 databases.

The SML qualifies as one of the best equipped medical libraries in the Middle East. Its collection consists of 188 printed periodical titles, over 84,000 backfile periodical volumes, more than 5,000 e-textbooks, and nearly 48,000 books. SML has a large number of the most important bibliographic medical and allied health databases, and provides access to more than 5,500 medical and health sciences e-journals.

The Engineering library includes: book and periodical collections, study area (64 seats), public computer lab (24 work stations), printers (2), scanners (2), and photocopy machines (3). The library houses the following collection: print books: 18,825 titles in 20,091 copies; print periodicals: 248 titles in 11,580 volumes; master degree theses: 1,002 titles in 1,032 volumes; non-book material (Videos, DVDs, CD-Roms, Discs, Slides, and Kits): 1,620 titles in 2,582 units. The library provides a rich online collection (e-journals and e-books) through subscriptions to major and professional institutional databases (abstract and full text) [Access is provided to 90,000 electronic journals and 200,000 electronic books in 250 databases] including Scopus, Web of Science, PubMed, Inspec, ACM Digital Library, ASME, ASCE, ASTM and BSI Standards, Elsevier ScienceDirect, Springer, Wiley-Interscience and many more.

These print and electronic collections are developed and enriched on a regular basis to support the academic and research programs of the University in all fields of study including biomedical sciences and engineering. The libraries are fully automated and many of their resources, databases, electronic books, and references are remotely accessible, providing a modern and virtual environment that is conducive to research. They are equipped with a state-of-the-art electronic classroom and computer laboratory. The libraries open a total of 106.5 hours per week and 24/7 during reading and exam periods.

**Laboratories and Research Equipment: FM and AUBMC**

The FM and AUBMC house a wide range of laboratories dedicated to teaching and research activities that are relevant to biomedical engineering. These laboratory facilities occupy a total of 5768 square feet mainly located in the DTS building. They include the following equipment and tools.

- **General laboratory equipment**: Gamma/beta scintillation counters, ultra, medium and low speed centrifuges, and a walk-in cold room. There are pH meters and balances (both analytical and top loading), tabletop centrifuges, shakers, microwave oven, circular water bath, micro-centrifuges, refrigerators (-20°C, -80°C freezers) and spectrophotometers.

- **Molecular Biology Core Facility**: The facility contains a DNA Sequencing facility, gel electrophoresis facility, an electroeluter, gene pulser, hybridization oven, UV cross linker, vacuum blotter, UV light boxes, multiple power supply units, dry bath, PCR in situ, Gene Amp in situ, 3 PCR machines, Real-Time PCR machine, gel dryer, a pulsed field electrophoresis unit and a Storm system (Molecular Dynamics-Amersham). A microarray
genechip equipment (Affymetrix) was recently added to the facility, a separate room is available for developing autoradiographs using the Kodak X-OMAT developing system. Two rooms are also available for working with radioactive isotopes. One is for work with high-energy isotopes and the other for working with low energy isotopes. The office of Radiation Safety has a separate receiving area for isotopes, which has its own independent entrance.

- **Protein Core Facility**: This facility is equipped with: Centrifuges (low, medium and ultraspeed) all refrigerated, Centrivap, FPLC, HPLC, Freezer -20, Freeze dryer, Gel dryer, Homogenizer, Multidrop ELISA plate dispenser, pH meter, Refrigerator, Rotator, Sonicator, Spectrophotometer UV/visible range, Spectrophotometer (Nano drop), Vacuum blotter, Water baths, 6 protein electrophoresis units, 2 Protean Xi PAGE, 2 EMSA units, transfer units, Electroeluters, Iso electrofocusing units and Bio-Dot microfiltration.

- **Infectious Diseases Research Core Facility (IDRCF)**: The IDRCF was established by a grant from the US Department of Defense and provides support for biomedical research. It is furnished with the following equipment: CHEF-MAPPER for Pulsed Field Gel Electrophoresis along with a Gel-doc apparatus, a dual head thermal cycler, a real time PCR machine, a Luminex apparatus and support equipment such as refrigerated microcentrifuge, small microcrafuge, shaker incubator, shaker water bath, horizontal electrophoretic chambers with power supplies, a UV hood for PCR, 2 freezers, a refrigerator and other small equipment.

- **Cell Culture Core Facility**: This facility contains: 9 CO2 incubators (two of which are dedicated P2 level for virally infected cells), 3 laminar flow hoods (one of which is dedicated for virally infected cells), microscopes, centrifuges, refrigerators for media, -20°C Freezer, luminometer, Water purifier, Water baths and 3 Liquid Nitrogen tanks.

- **Animal Care Facility (ACF)**: This renovated facility is in compliance with rules and regulations of the US Public Health Service (PHS) policy, the “Animal Welfare Act” and the Guide for the Care and Use of Laboratory Animals, NIH Research Council. Complementary to the ACF operation, the AUB has established an “Institutional Animal Care and Use Committee” (IACUC) to oversee the quality of care and utilization of vertebrate animals used in research, teaching, training and testing. The ACF has a surface area of 1100 m2. The physical facility includes two HEPA filtered operating rooms and one virtual setup, a post operating room with an “Intensive Care Unit”, a laboratory, a necropsy room, a quarantine room, several rooms for housing experimental animals, a HEPA filtered breeding facility, a HEPA filtered Transgenic Unit in which transgenic animals such as immunodeficient are housed, a microsurgery facility.

- **Biological Imaging Core Facility**: A comprehensive biological imaging facility consists of a computer controlled laser scanning confocal microscope (Zeiss LSM 410 and an LSM 710) with 2 lasers (Ar/Kr and HeNe) and a compliment of high NA DIC and fluorescent lenses and a video-based imaging photometry system with multi wavelength excitation capability (PTI Image master and Oscar) with an intensified CCD camera for the detection of low signals as
well as the ability to measure in real time dynamic processes and an edge detection
capability. In addition, a fluorescence microscope system is available.

- **Environmental Core Facility**: Established in 1997 through a generous support by USAID, the
  Environment Core Laboratory (EVL) provides a broad range of analytical chemistry services
  or municipal, agricultural, engineering, and industrial clients in the local and regional
  communities. In 2008, EVL received additional support through Lebanon’s Ministry of
  Economy and Trade QUALEB quality program, an EU funded project, in support of analytical
  services for the food and agri-food industry. The Environment Core Laboratory (EVL) is
  furnished with state-of-the-art equipment for the extraction, analysis and identification of a
  vast array of inorganic and organic chemicals. EVL applications ranges from identification of
  contaminants in different environmental matrices (e.g. water, waste water, soil, compost.),
  food and agri food products (raw, processed and canned), and non-edible oil analysis (such
  as gasoline, diesel and industrial oil), to food chemistry and microbiology such as nutritional
  labeling, pesticides residues, heavy metals, colorants, allergens, and aflatoxins. EVL services
  also cover pharmaceutical products, occupational and public health research and diagnostic
  medical services such as organic acids, trace and heavy metals, tobacco metabolites
  (nicotine, cotinine, 1-HOP) and exposure to specific organic pollutants and its metabolites
  in biological specimens (hair, semen, blood, urine, teeth and body fluids). EVL facilities
  consist of the following laboratory divisions: inorganic, organic, and microbiology
  laboratories.

**Laboratories and Research Equipment: FEA**

The FEA houses a wide range of laboratories dedicated to teaching and research activities in
various engineering disciplines; many of these laboratories are relevant to biomedical
engineering. Additionally, some individual faculty members with research interests in
Biomedical Engineering have their individual lab/equipment setups. These laboratory facilities
are mainly located in the RGB, SRB, and IOE buildings. They include the following equipment
and tools.

- **Biomedical Engineering Laboratory**: EEG measurements are conducted in this laboratory.
  The data collected is then utilized to understand the relationship between the voltage
  measured and the brain activity. The equipment in the laboratory is state-of-the art and
  utilizes the active probe technology. The laboratory includes a bio-semi active probe 64-
  channel EEG machine and a ViSaGe MKII stimulus generator.

- **Robotics and Instrumentation Laboratory**: In this laboratory, students learn the
  fundamentals of instrumentation and robotics. New sensors both wired and wireless have
  been acquired for the laboratory. In the robotics lab, five mobile robots with full wireless
  control have been added to the two already existing manipulators. In 2011, the family of
  robots was expanded to include there humanoids, a quad rotor Aarial robot and a six meter
  long autonomous blimp. Moreover, the laboratory includes a variety of data acquisition
  systems (USB and PCI), SCXI chassis with several signal conditioning modules, a variety of
sensors (strain gauge, pressure, force, temperature, weight, oxygen, conductivity, etc.), and
temperature calibrators.

- **Signal and Image Processing Laboratory:** In this laboratory, students carry out experiments
  in digital signal, image, and speech processing. Equipment includes DSP kits provided by
  Texas Instruments, audio synthesizers, computers and multimedia accessories. The
  laboratory was recently equipped with state of the art audio equipment that allowed the
  offering of an elective course in audio engineering. In 2011, the laboratory acquired several
  high end VGA boards that enabled the teaching of GPU programming using CUDA. The
  laboratory includes NVIDIA GPU boards and Tesla GPU boards, TMS320VC55 DSP starter kit,
  TMDSVDP6437, TMS320DM6437 video starter kit, TMS320DM355 digital video evaluation
  module, oscilloscopes, function generators, power supplies, and multi-meters.

- **Multi-core Programming Laboratory:** This laboratory was established with the help of a
generous donation from Intel and was inaugurated during the fall semester of AY 2008-09.
  This laboratory is used to teach students the techniques of writing software programs that
  takes full advantage of multi-core processor technology. The techniques taught allow
  students to run simulation software fast and efficiently. The hardware in the laboratory
  consists of two Intel 2U Server with Xeon Quad Core 2.33GHz, seven Intel PC with Xeon
  Quad core 2.66GHz, and eight Intel PC with Xeon Duo Core 2.66GHz mini-tower.

- **Sun Computing Cluster:** It consists of ten Sun-Blade 150 machines and ten Sun-Blade 1500
  machines. In addition to these workstations, the cluster is managed by a quad-processor
  Sun-Fire 440 server. The Sun computational grid is accessible from any terminal and runs a
  number of simulation software.

- **The Environmental Engineering Research Center (EERC):** This laboratory occupies an area
  of 240 square meters; it is equipped for the assessment of a wide range of analytical
  parameters having environmental as well as public health significance. The EERC serves
  both as a research facility as well as a community service laboratory. As a research center,
  the facility allows faculty and students to conduct experiments and research investigating
  physical, chemical, and biological contaminants associated with major environmental
  matrices such as water, municipal and industrial wastewaters, sludge, soils, leachate, solid
  wastes, sediments, compost, and air. Also, package experimental setups are available to
  instruct students on various treatment processes such as ion exchange, filtration, aeration,
  reverse osmosis, sedimentation studies, aerobic digestion, anaerobic digestion, and
  permeability/fluidization. The lab comprises state-of-the-art analytical instrumentation
  including, among others, GC/MS, LC/MS/MS, GFAAS, and PCR-DGGE equipment.

- **Aerosol Research Laboratory:** This facility is home to an interdisciplinary research group
  with backgrounds in aerosol dynamics, biochemistry, combustion, computational fluid
  dynamics, instrumentation, and controls. Faculty use the facilities to produce policy-
  relevant science with thematic focuses on tobacco smoke, urban and indoor air pollution
  and its sources, and atmospheric aerosol volatility. Several novel instruments for waterpipe
  tobacco smoking research have been developed at the laboratory, including a waterpipe
smoking topography device, an in-situ real-time sampling device for waterpipe smoke analysis, and a tobacco-smoking robot that can mimic human puffing behavior in detail resolved to 100 ms. The facility is equipped with a variety of particle sampling, sizing, and generation instruments as well as laminar and plug-flow thermodenuders and a 1 m³ well-stirred reactor.

- **Experimental Fluids Laboratory:** This facility houses state-of-the-art equipment for advanced optical diagnostics of liquid and gaseous flows. It has an L-shaped open loop wind tunnel with a square cross-sectional area that measures (18 in X 18 in X 36 in) and can generate steady wind speeds in the test section from nearly 3 m/s to 50 m/s in 1 m/s increments with low turbulence intensities. Available wind tunnel tests include smoke visualization, particle image velocimetry, particle tracking velocimetry, surface pressure measurements, and lift and drag estimation using a 2-axis dynamometer. The cross-correlation PIV system was designed and assembled in-house, and can thus be adapted to a wide range of gas/liquid flows and measurement requirements. The PIV system has been adapted to acquire laser induced fluorescence measurements and particle tracking velocimetry. Other equipment include a pulsed YAG laser, continuous HeNe and Ar Ion lasers, fast shuttered cameras, and fast rise time photo-detectors.

- **Material Characterization Laboratory:** This facility supports teaching pertaining to engineering materials, promotes applied research in materials science, and provides much-needed consulting, contract testing, and other services for outside parties including local factories and industrial facilities. It includes a universal testing machine, several optical and digital microscopes, inverted metallurgical microscopes, a furnace, a heat treatment furnace, an induction melting oven and a microstructure polishing station.

- **Thermal Fluids Laboratory:** This facility consists of several fluid mechanics, heat transfer, and heat engine experimental apparatuses to support thermodynamics, heat transfer, and fluid mechanics experiments. Equipment consist of commercially packaged bench-top experiments in heat transfer (convection and radiation), heat engines (vapor-compression cycle heat pump, Rankine cycle steam power plant), water turbine (a Pelton wheel), pipe friction measurement setup, and flow visualization (a smoke tunnel).

**Laboratories and Research Equipment: Others**

- **Kamal Shair Central Research Science Laboratory (KSCRSL):** KSCRSL is a research facility managed by the Faculty of Arts and Sciences (FAS). The KSCRSL has been remodeled according to the specifications and needs of modern research laboratories and is at a walking distance from the FEA. This facility complements departmental research laboratories, and as such aims at promoting individual, as well as joint and multidisciplinary co-operative research. This facility serves research in most disciplines including the basic sciences (biology, chemistry, geology, and physics), medicine, health sciences, agricultural and food sciences, and engineering. The KSCRSL is therefore designed primarily to serve AUB faculty members, their graduate students, and their research collaborators. The facility
has an area of 3000 m2 and provides access to state-of-the art instrumentation. Instruments include, but are not limited to, Flow Cytometer with sorter, Fluorescence imaging microscope, Quantitative PCR, gel documentation system, atomic absorption spectrophotometer, a bioreactor, centrifuges, dark room, ELISA reader and washer, HPLC and HPLC MS, laminar flow hood, NMR spectrometer, and uv/vis/nir Spectrophotometer. Two Biomedical Engineers have been appointed by the FAS to oversee the status and maintenance of equipment in the KSCRSL.
6. FACULTY

The FEA and FM have diverse interests in research that meet to a large extent the educational needs of the proposed program. Moreover, new faculty members will be recruited, as needed, in the FEA and FM to support the establishment of the new graduate programs in Biomedical Engineering. In order to support the graduate programs in Biomedical Engineering, FEA plans to recruit four new faculty members and FM plans to recruit two new faculty members in the next three years, with possibilities for joint appointments. The areas of expertise of the recruited faculty members will be in line with the focus areas of the proposed curriculum. The tables below present a list of selected existing faculty members that have interests and/or ongoing research activities related to Biomedical Engineering in both FEA and FM, respectively.

<table>
<thead>
<tr>
<th>Faculty Member [FEA]</th>
<th>Department</th>
<th>Biomedical Related Research Interests</th>
</tr>
</thead>
<tbody>
<tr>
<td>N. Ghaddar, K. Ghali</td>
<td>ME</td>
<td>Blood flow modeling; bioheat modeling</td>
</tr>
<tr>
<td>W. Saad, M. Hindi</td>
<td>CHEN</td>
<td>Nanomaterials; drug delivery</td>
</tr>
<tr>
<td>H. Hajj, M. Awad, R. Kanj, F. Zaraket</td>
<td>ECE</td>
<td>Pattern recognition; data mining; neural networks</td>
</tr>
<tr>
<td>N. Sabah, F. Karameh</td>
<td>ECE</td>
<td>Neuroscience, neuroengineering; signal/image processing</td>
</tr>
<tr>
<td>M.A. Al-Alaoui</td>
<td>ECE</td>
<td>Signal and image processing; neural networks; pattern recognition</td>
</tr>
<tr>
<td>I. Elhajj, A. Kayssi, A. Chehab</td>
<td>ECE</td>
<td>Automated diagnosis; devices; modeling and simulation</td>
</tr>
<tr>
<td>M. Abou Zeid, I. Kaysi</td>
<td>CEE</td>
<td>Physiological monitoring</td>
</tr>
<tr>
<td>A. Shihadeh</td>
<td>ME</td>
<td>Smoking health effect; lung bubble oscillation modeling</td>
</tr>
<tr>
<td>D. Salam</td>
<td>CEE</td>
<td>Polymers formations from vegetable oils and their implication in cardiovascular diseases</td>
</tr>
<tr>
<td>Z. Mouwafq</td>
<td>ECE</td>
<td>Computational genomics and bioinformatics</td>
</tr>
<tr>
<td>F. Moukal</td>
<td>ME</td>
<td>Computational modeling; fluid mechanics</td>
</tr>
<tr>
<td>G. Oweis</td>
<td>ME</td>
<td>Blood flow modeling; non-invasive focused ultrasound</td>
</tr>
<tr>
<td>R. Hamade</td>
<td>ME</td>
<td>Biomechanics; telehaptic surgery; teleoperation</td>
</tr>
<tr>
<td>M. Liermann</td>
<td>ME</td>
<td>Pneumatic systems and robotic devices</td>
</tr>
</tbody>
</table>

CEE (Civil and Environmental Engineering), CHEN (Chemical Engineering), ECE (Electrical and Computer Engineering), ME (Mechanical Engineering)

<table>
<thead>
<tr>
<th>Faculty Member [FM]</th>
<th>Department</th>
<th>Biomedical Related Research Interests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jaffa, Ayad</td>
<td>Biochemistry and Molecular Genetics</td>
<td>Cardiovascular diseases; vascular biology and remodeling; molecular signatures of diabetic complications</td>
</tr>
<tr>
<td>Darwiche, Nadine</td>
<td>Biochemistry and Molecular Genetics</td>
<td>Anticancer drug development and drug delivery systems; signaling; epigenomics and genomics in cancer</td>
</tr>
<tr>
<td>Name</td>
<td>Department</td>
<td>Research Area</td>
</tr>
<tr>
<td>-----------------------</td>
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<td>-------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Nemer, Georges</td>
<td>Biochemistry &amp; Molecular Gen</td>
<td>Bioinformatics</td>
</tr>
<tr>
<td>Eid, Assad</td>
<td>Physiology</td>
<td>Renal and cardiovascular system; drug delivery systems</td>
</tr>
<tr>
<td>Zeidan, Asad</td>
<td>Physiology</td>
<td>Vascular smooth muscle cells; tissue engineering</td>
</tr>
<tr>
<td>Sabban, Marwan</td>
<td>Physiology</td>
<td>Interaction between host tissues and cancer cells; tissue engineering and the use of differentiated stem cells in discovery and screening</td>
</tr>
<tr>
<td>Daoud, Georges</td>
<td>Physiology</td>
<td>Placental development and the exchange interface between maternal and fetal blood</td>
</tr>
<tr>
<td>Habib, Robert</td>
<td>Internal Medicine</td>
<td>Bio-fluid mechanics; respiratory mechanics; bio-systems identification; health data mining and analysis</td>
</tr>
<tr>
<td>Refaat, Marwan</td>
<td>Internal Medicine</td>
<td>Remote monitoring devices for cardiac arrhythmias; biomedical/health informatics; fluid mechanics, modeling, simulation and imaging</td>
</tr>
<tr>
<td>Jaroudi, Wael</td>
<td>Internal Medicine</td>
<td>Cardiac CT angiography and predicting significant stenosis</td>
</tr>
<tr>
<td>Badr, Kamal</td>
<td>Vascular Medicine Program</td>
<td>Vascular inflammation; hypertension; mechano-inflammatory injury</td>
</tr>
<tr>
<td>Rassi El, Issam</td>
<td>Surgery</td>
<td>3D imaging, modeling, and 3D printing of malformed hearts, before and after treatment</td>
</tr>
<tr>
<td>El Hajj, Hiba</td>
<td>Internal Medicine</td>
<td>Molecular oncology</td>
</tr>
</tbody>
</table>

It is important to highlight that the FEA has already opened two positions related to Biomedical Engineering during the academic year 2012-13. More than 30 applications were received mostly from doctoral holders working in the USA. A search committee was set and went through a selection process that resulted in short listing and inviting to interviews five applicants. As a result, two distinguished applicants were recommended and offered positions to join the FEA during the academic year 2013-14; one has already accepted the offer and expected to join beginning of 2014, whereas the second one requested some extension before taking a final decision.

The new faculty lines will be in the general area of Biomedical Engineering with focus on expertise that include biomaterials, cardiovascular and pulmonary engineering, computational modeling, biomedical systems, etc.

In order to optimize the use of the new faculty lines, newly introduced biomedical engineering courses will be also open to students from other relevant departments across campus that will include students from biomedical sciences, various existing engineering disciplines, biology, chemistry, physics, health sciences, etc. Moreover, biomedical engineering students will be also required to take existing courses given on a regular basis by faculty members in the FEA and FM, as included in the curriculum design.

No new administrative staff are planned to be hired to help in program coordination and administration. Administrative support will be provided by staff members that have been assigned by the Dean to work with the program coordinator.
7. CURRICULUM

Program Research Focus Areas
The DBME will be initially composed of three research focus areas that have been carefully selected based on existing expertise, available resources, and potential impact. These are:

- **Biomedical Systems**: This focus area includes research directions such as devices, instrumentation, biomechanics, biomaterials, drug delivery systems, and tissue engineering.

- **Biomedical Cybernetics**: This focus area includes research directions such as biomedical and health informatics, computational biology, biomedical signal/image processing, and biomedical systems engineering.

- **Cardiovascular and Pulmonary Engineering**: This focus area includes research directions such as fluid mechanics, modeling, simulation, imaging, devices, and implants related to both human cardiovascular and pulmonary systems.

These focus areas were also benchmarked against existing established biomedical engineering programs at US universities such as John Hopkins, Columbia, UCLA, Duke, Boston, University of Pennsylvania, Case Western, etc. Based on the benchmarking exercise, it was noticed that the focus areas at the graduate level are quite different among universities and customized based on available resources and existing areas of interest (see Appendix A for a comparative analysis).

It is important to highlight that the MBME curriculum is designed using a modular approach which facilitates the smooth addition of new focus areas in the future, as deemed important and feasible, in order to further expand the program’s scope.

Degree Requirements
Requirements for Bachelor’s degree holders: Two types of Master’s degree programs will be offered, namely, thesis and non-thesis degrees.

- Students following the thesis option are required to complete a minimum of 30 credit hours of which 21 graduate credit hours are in course work and nine credit hours of thesis work. Normally, a maximum of three credit hours may be tutorial courses. Exceptions for individual students will require approval of the Program Coordinator and the FEA and/or FM Faculty Graduate Studies Committees.

- Students following the non-thesis option are required to take a minimum of 30 graduate credit hours, three credits of which may be a project and should follow a course of study approved by the Program Coordinator and by the FEA and/or FM Faculty Graduate Studies Committees.
**Curriculum Design**

The proposed curriculum has been designed after undertaking a critical assessment of available strengths, opportunities, and constraints in establishing and maximally supporting a successful interdisciplinary graduate program in Biomedical Engineering that is customized for AUB. Therefore, the Committee designed a flexible modular interdisciplinary curriculum that is well founded in both biomedical sciences and engineering and, thus, can be tailored to applicants with different backgrounds and research interests.

The Committee has also assessed several top ranked programs in biomedical engineering in the USA. The general aim of this comparison exercise was to:

- Ensure program quality when designing a required set of core background undergraduate courses in biomedical engineering.
- Verify program flexibility in providing the students with a wide set of possible specialization areas along with the necessary core graduate courses.
- Assess program competitiveness by benchmarking against successful doctoral programs in the selected focus areas.

The MBME curriculum design is divided into three layers as presented in the below diagram:

```
<table>
<thead>
<tr>
<th>Background Undergraduate Sciences Courses [up to 10 cr.]</th>
<th>Customized based on applicant’s entry major, degree, and track</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background Undergraduate Engineering Courses [up to 24 cr.]</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>List I: Core Graduate Courses [9 cr.]</th>
<th>Customized based on student’s track with controlled level of flexibility in the selection:</th>
</tr>
</thead>
<tbody>
<tr>
<td>List II: Core Graduate Courses [9 cr.]</td>
<td>- Total graduate level credits for thesis option: 30 cr. [21 cr. courses and 9 cr. thesis]</td>
</tr>
<tr>
<td>Elective Graduate Courses</td>
<td>- Total graduate level credits for non-thesis option: 30 cr. [all courses]</td>
</tr>
<tr>
<td>- Thesis option: [3 cr.]</td>
<td>- Elective graduate courses: customized per student as approved by advisor(s)</td>
</tr>
<tr>
<td>- Non-Thesis Option: [12 cr.]</td>
<td></td>
</tr>
</tbody>
</table>
```
Layer I – Background Undergraduate Courses (BUC): With the proposed program targeting applicants with diverse backgrounds, effort was made to ensure that admitted students have the minimum set of core background knowledge and tools that allow them to efficiently commence their graduate-level tenure in the program. This is needed because there is no undergraduate program in biomedical engineering at AUB and, thus, a major subset of admitted students will come from different majors.

The requirements were developed after consulting several ABET-accredited top-ranked undergraduate programs in biomedical engineering, including the curricula at Johns Hopkins University, Duke University, and Boston University (see Appendix A for comparative analysis).

Table 1: Background Undergraduate Courses in Sciences

<table>
<thead>
<tr>
<th>Course #</th>
<th>Course Title</th>
<th>Biomedical Systems (10 cr.)</th>
<th>Biomedical Cybernetics (10 cr.)</th>
<th>Cardiovascular Engineering (10 cr.)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL201</td>
<td>General Biology (4cr.)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>CHEM211</td>
<td>Organic Chemistry (3cr.)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>CHEM217</td>
<td>Thermodynamics (3cr.)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>MECH310,CHEN314</td>
</tr>
</tbody>
</table>

Table 2: Background Undergraduate Courses in Engineering

<table>
<thead>
<tr>
<th>Course #</th>
<th>Course Title</th>
<th>Biomedical Systems (24 cr.)</th>
<th>Biomedical Cybernetics (21 cr.)</th>
<th>Cardiovascular Engineering (21 cr.)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECE210</td>
<td>Electric Circuits (3 cr.)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>EECE230</td>
<td>Programming (3 cr.)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>EECE290</td>
<td>Analog Signal Processing (3 cr.)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>MECH314</td>
<td>Introduction to Fluids</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>CHEN311, CIVE340</td>
</tr>
<tr>
<td>MECH340</td>
<td>Engineering Materials (3 cr.)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Background Engineering Courses Required by all Focus Areas (15 cr.)

Background Engineering Courses Specialized per Focus Area (6-9 cr.)

<table>
<thead>
<tr>
<th>Course #</th>
<th>Course Title</th>
<th>Biomedical Systems (24 cr.)</th>
<th>Biomedical Cybernetics (21 cr.)</th>
<th>Cardiovascular Engineering (21 cr.)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>MECH412</td>
<td>Heat and Mass Transfer (3 cr.)</td>
<td>X</td>
<td></td>
<td>X</td>
<td>CHEN411</td>
</tr>
<tr>
<td>EECE310</td>
<td>Electronics (3 cr.)</td>
<td>X</td>
<td></td>
<td></td>
<td>EECE312</td>
</tr>
<tr>
<td>EECE330</td>
<td>Data Structures and Algorithms (3 cr.)</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EECE340</td>
<td>Signals and Systems (3 cr.)</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>MECH430</td>
<td>Instrumentation and Measurements (3 cr.)</td>
<td></td>
<td></td>
<td></td>
<td>EECE461</td>
</tr>
</tbody>
</table>

For applicants with an engineering background, most engineering undergraduate programs at AUB are ABET accredited; accordingly, many of the courses listed above are included as part of the curricular requirements for theses disciplines. For applicants from natural sciences disciplines, it is expected that the chemistry and biology courses in addition to prerequisite
mathematics and physics courses be covered in their undergraduate degree; however, they would need to take around one year of background undergraduate engineering courses. This is relatively fair since an undergraduate Bachelor of Engineering (BE) degree at AUB requires 143 credit hours over four years including summers, whereas an undergraduate Bachelor of Science (BS) degree at AUB requires 90 credits for students entering as sophomores over three years. In general, students are required to take any additional prerequisite courses needed for the background undergraduate courses, core graduate courses, or elective graduate courses, unless they are formally exempted.

**Layer II – Core Graduate Courses (CGC):** The second layer in the curriculum design is the most important as it includes the set of required core graduate courses in biomedical sciences and engineering. These courses are customized based on the three adopted research focus areas: Biomedical Systems, Biomedical Cybernetics, and Cardiovascular and Pulmonary Engineering. The total number of credits per focus area for core graduate courses is 18 credits distributed among two lists (List I and List II) including both biomedical sciences and engineering courses (see Tables 3 and 4); these core courses are complemented with additional elective course based on the student’s interest and area of specialization: 3 credits for thesis program and 12 credits for non-thesis program. This results in a total of 21 credits for thesis option and 30 credits for non-thesis option in graduate course work which meets AUB’s requirements of graduate course work after the Bachelor’s degree.

**Table 3: List I of Core Graduate Courses**

<table>
<thead>
<tr>
<th>Course #</th>
<th>Course Title</th>
<th>Biomedical Systems (9 cr.)</th>
<th>Biomedical Cybernetics (9 cr.)</th>
<th>Cardiovascular Engineering (9 cr.)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPHD310*</td>
<td>Biostatistics (3 cr.)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>HUMR314</td>
<td>Seminar Course (0 cr.)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>BIOC321</td>
<td>Nucleic Acids and Basic Genetics (1 cr.)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>BIOC322</td>
<td>Protein Biochemistry (1 cr.)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHYL300</td>
<td>Pulmonary Physiology (2 cr.)</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHYL302</td>
<td>Cardiovascular Physiology (2 cr.)</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAAAxxx</td>
<td>Quantitative Physiology (3 cr.)</td>
<td>X</td>
<td>X</td>
<td></td>
<td>New</td>
</tr>
<tr>
<td>BBBBxxx or BBBBxxx</td>
<td>Biomedical Instrumentation Lab (1 cr.)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>New</td>
</tr>
<tr>
<td></td>
<td>Biomedical Signal Analysis Lab (1 cr.)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>New</td>
</tr>
</tbody>
</table>

* EPHD310 can be replaced by another advanced level statistics course based on advisor’s approval.
Table 4: List II of Core Graduate Courses

<table>
<thead>
<tr>
<th>Course #</th>
<th>Course Title</th>
<th>Biomedical Systems (9 cr.)</th>
<th>Biomedical Cybernetics (9 cr.)</th>
<th>Cardiovascular Engineering (9 cr.)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEN672</td>
<td>Polymer Science (3 cr.)</td>
<td>A1*</td>
<td></td>
<td>E1</td>
<td>⊙ MECH627</td>
</tr>
<tr>
<td>EECE601</td>
<td>Biomedical Engineering I (3 cr.)</td>
<td>B1</td>
<td></td>
<td>E1</td>
<td></td>
</tr>
<tr>
<td>EECE603</td>
<td>Biomedical Signal &amp; Image Processing (3 cr.)</td>
<td></td>
<td>C1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EECE663 or EECE633 or EECE693 or EECE667</td>
<td>System Identification (3 cr.) or Data Mining (3 cr.) or Neural Networks (3 cr.) or Pattern Recognition (3 cr.)</td>
<td></td>
<td>C2</td>
<td>E2**</td>
<td>⊙ MECH656</td>
</tr>
<tr>
<td>MECH633</td>
<td>Biomechanics (3 cr.)</td>
<td>B2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBBBxxx</td>
<td>Cardiovascular/Pulmonary Fluid Mechanics (3 cr.)</td>
<td></td>
<td>F1</td>
<td>New [or MECH660]</td>
<td></td>
</tr>
<tr>
<td>BBBBxxx</td>
<td>Tissue Engineering and Biomaterials (3 cr.)</td>
<td>A2</td>
<td></td>
<td>E3</td>
<td>New [or MECH634]</td>
</tr>
<tr>
<td>BBBBxxx</td>
<td>Computational Modeling of Physiological Systems (3 cr.)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBBBxxx</td>
<td>Quantitative Analysis and Modeling of Cardiovascular/Pulmonary Systems (3 cr.)</td>
<td></td>
<td>X</td>
<td></td>
<td>New</td>
</tr>
<tr>
<td>AAAAxxxx</td>
<td>Biomedical Diagnostic Imaging (3 cr.)</td>
<td></td>
<td>D1</td>
<td>F2</td>
<td>New</td>
</tr>
<tr>
<td>AAAAxxxx</td>
<td>Bioinformatics and Proteomics (2 cr.)</td>
<td></td>
<td>D2</td>
<td></td>
<td>New</td>
</tr>
<tr>
<td>AAAAxxxx</td>
<td>Cell Signaling in Health and Disease (1 cr.)</td>
<td></td>
<td>D2</td>
<td></td>
<td>New</td>
</tr>
</tbody>
</table>

* Students can choose one course from the following groups {A1, A2}, {B1, B2}, {C1, C2, C3}, etc.
** E2 can be only EECE663 System Identification; C2 can be any of the four listed courses.

The Committee has also reviewed a large set of biomedical engineering graduate programs. This exercise revealed salient features of such programs that are also covered in the proposed curriculum as applicable within the three selected focus areas. Appendix A presents a comparative analysis with respect to biomedical engineering doctoral programs in selected universities, namely Johns Hopkins University (JHU), Duke University (DUKE), and University of Pennsylvania (UPenn).

Layer III – Elective Graduate Courses (EGC): Depending on the needs of their specific area of research and based on the recommendation of the thesis advisors, Master’s students are required to take at 3 credits in elective graduate courses for the thesis option and 9 credits in elective graduate courses for the non-thesis option. These courses will be selected from a large set of available graduate courses at AUB that could be relevant to students’ interests and focus areas in biomedical engineering; these can include specialized courses from biomedical sciences, various engineering disciplines, computer science, mathematics, natural sciences,
health sciences, etc. Table 5 presents a selected non-comprehensive set of available courses that can be taken as electives from biomedical sciences and engineering. The aim is to demonstrate that AUB has a wide range of available courses that are offered on a regular basis and that would be of potential interest to graduate students majoring in Biomedical Engineering.

Table 5: Sample Non-Comprehensive List of Available Elective Courses in Biomedical Sciences and Engineering

<table>
<thead>
<tr>
<th>Relevant to Biomedical Systems Research Focus Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomedical Sciences: MBIM 330 Molecular Microbiology (3 cr.), HUMR 310 Methods in Biomedical Sciences (3 cr.), PHYL 310 Cell Physiology and Biophysics, IDTH 204 Basic Pathological Mechanisms (2 cr.), IDTH 301 Introduction to Medical Science Literature (2 cr.), BIOC 302 Developmental Biochemistry (3 cr.), BIOC 303 Molecular Biology of Cancer (3 cr.), BIOC 316 Bioinformatics (1 cr.), etc.</td>
</tr>
</tbody>
</table>

| Engineering: CHEN 673 Engineering of Drug Delivery Systems (3 cr.), EECE 612 Digital Integrated Circuits (3 cr.), EECE 617 Reliability and Statistical Design (3 cr.), EECE 625 Embedded Systems Design (3 cr.), MECH 609 Experimental Fluid Dynamics (3 cr.), MECH 631 Micro Electro Mechanical Systems (MEMS) (3 cr.), MECH 634 Biomaterials and Medical Devices (3 cr.), MECH 641 Robotics (3 cr.), MECH 646 Wheeled Mobile Robots, etc. |

<table>
<thead>
<tr>
<th>Relevant to Biomedical Cybernetics Research Focus Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomedical Sciences: HUMR 310 Methods in Biomedical Systems (3 cr.), HUMR 308A Neuroanatomy (3 cr.), HUMR310B Genomics and Proteomics (1 cr.), IDTH 310 Basic Pathological Mechanisms 92 cr., IDTH 301 Introduction to Medical Science Literature (2 cr.), IDTH 307 Biomedical Electronics (3 cr.), BIOC 303 Molecular Biology of Cancer (3 cr.), BIOC 316 Bioinformatics (1 cr.), etc.</td>
</tr>
</tbody>
</table>

| Engineering: CIVE 671 Numerical Modeling (3 cr.), EECE 604 Communications Engineering for Genetics and Bioinformatics (3 cr.), EECE 605 Neuromuscular Engineering (3 cr.), EECE 631 Advanced Topics in Algorithms, EECE 637 Advanced Programming Practice (3 cr.), EECE 664 Fuzzy Sets, Logic, and Applications (3 cr.), EECE 694 Digital Image Processing (3 cr.), MECH 642 Computer Vision (3 cr.), MECH 630 Finite Element Methods in Mechanical Engineering (3 cr.), MECH 648 Nonlinear Systems: Analysis, Stability, and Control (3 cr.), MECH 654 System Analysis and Design (3 cr.), MECH 663 Computational Fluid Dynamics (3 cr.), MECH 705 Bioheat Modeling and Human Thermal Environments (3 cr.), etc. |

<table>
<thead>
<tr>
<th>Relevant to Cardiovascular and Pulmonary Engineering Research Focus Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomedical Sciences: HUMR 310 Methods in Biomedical Systems (3 cr.), PHYL 300 Homeostasis (2 cr.), PHYL 310 Cell Physiology and Biophysics (3 cr.), IDTH 301 Introduction to Medical Science Literature (2 cr.), BIOC 306 Mediators in Vascular Biology and Inflammation (2 cr.), PHRM 300 Pharmacology and Toxicology (3 cr.), etc.</td>
</tr>
</tbody>
</table>

| Engineering: CHEN 672 Polymer Science (3 cr.), CHEN 673 Engineering of Drug Delivery Systems (3 cr.), CIVE 710 The Finite Element Method (3 cr.), MECH 607 Micro Flows Fundamentals and Applications (3 cr.), MECH 609 Experimental Fluid Dynamics (3 cr.), MECH 634 Biomaterials and Medical Devices (3 cr.), MECH 642 Computer Vision (3 cr.), MECH 648 Nonlinear Systems: Analysis, Stability, and Control (3 cr.), MECH 663 Computational Fluid Dynamics (3 cr.), etc. |
Curriculum Design Summary
The principle behind the choice of this multi-layered curriculum design is to offer students with the skills, scientific insight, critical knowledge and attitudes and behaviors necessary to pursue advanced research in the chosen biomedical engineering discipline. In addition, students must build up depth of knowledge, and broaden that knowledge by asking pertinent questions and designing experiments that result in the advancement of science. Students must engage in critical thinking and also acquire skills to articulate and clearly discuss scientific principles and data. In parallel, students must learn the ethical principles and professional behaviors that guide scientific inquiry. This is achieved by requiring the students to take a wide range of courses balanced between engineering and medical sciences, and complemented by skills and hands-on oriented components such as a seminar course with invited speakers from industry and academia to discuss emerging topics and a lab course.

Thesis Dissertation Requirements [Details based on Graduate Catalogue 2013-14, pp. 55-60]
To meet the minimum residence requirements for the Master’s degree, a student must register and be in residence as a graduate student for at least two semesters, one semester and two summers, or four summers. All requirements for the Master’s degree must be completed within a period of four years after admission to graduate study. Students attending only summer sessions must complete all requirements within a period of six summers after admission to graduate study. Extension beyond the maximum allowed period of study requires approval from the Faculty Graduate Studies Committee.

Thesis Proposal: Master’s students are expected to meet with faculty members in the program to discuss with them possible thesis topics and arrange to have a thesis adviser. Normally, the thesis adviser is from among the full-time professorial faculty of the Program or from another department/program in the University. The student is expected to select a research topic in consultation with the thesis adviser and prepare a thesis proposal by the end of the second regular semester. The proposal must clearly state the problem addressed and the proposed contributions. The thesis proposal should also state the thesis objectives, scope of work with relevant literature, research methodology, and expected results.

A thesis committee is formed by the thesis adviser and the student in coordination with the Program Coordinator. The Thesis committee should normally consist of at least three members from the professorial ranks chaired by the thesis adviser. The committee members will evaluate the proposal in consultation with the thesis adviser. The student will submit the thesis proposal with a completed Thesis Proposal form as required by Program (Website) to the Program Coordinator, signed by the thesis adviser and all the members of the thesis committee, with the proposed dates of the comprehensive examination, and thesis defense, and courses taken so far. The student should indicate if the proposed research involves human subject research or animal related research and seek approval/confirmation or exemption of the Institutional Review Board and/or the Animal Care Committee. Once approved, the
Program Coordinator forwards the thesis proposal with the names of the thesis committee members to the FEA and FM Graduate Studies Committees for their approval.

**Comprehensive Exam:** Students are required to register and pass a zero-credit comprehensive examination course. The comprehensive exam is an oral exam and taken after completing most of the course requirements for the degree and submitting the thesis proposal. Timing of the examination is set by the thesis advisor in consultation with the Program Coordinator with a grade of Pass (P) or Fail (F). A student who does not pass the comprehensive examination may take it a second time in the following semester. Students who are unable to pass a program’s comprehensive exam twice are dropped from the graduate program.

**Thesis Defense:** A student is not allowed to defend his/her thesis unless he or she has passed the comprehensive examination. In order to defend the thesis, the student must be registered for the thesis in the session in which the student expects to graduate. The thesis defense is open to the public and must be carried out no later than the deadline dates set by the University Graduate Council. The thesis defense session is normally chaired by the thesis adviser and the student will be notified of the final decision by thesis committee immediately after completion of the thesis committee deliberations. Pass (P) or Fail (F) is reported for the combined thesis and thesis defense. If Fail (F) is reported, the student may resubmit the thesis and defend it after a period of at least three months. Failure on the second attempt results in discontinuation of the graduate work. If the thesis work involves human subject research or animal related research, the thesis committee must forward to the department chair a copy of the approval/confirmation or exemption letter of the Institutional Review Board and/or Animal Care Committee. After passing the thesis defense examination, the student is required to deposit copies of the thesis in the Jafet Memorial Library.

**Master’s Degree Graduation Requirements:** To be eligible for graduation with a Master’s degree from the American University of Beirut, a graduate student:
- must have attained a cumulative course average of 80 or above.
- is not placed on probation by the time the course work is completed.
- must have completed the minimum credit hours of course work designated by the specific program.
- must have passed comprehensive exam.
- must have completed thesis requirements for thesis option degrees.
- must have completed course requirements for the non-thesis option degrees.
- must have met the residence requirements specified for the Master’s degree.
8. STUDENTS

The BMEP is expected to start with two new students enrolled per year at the PhD level and five students enrolled per year at the Master’s level. The table below provides data on projected enrollment over a six year period until steady state capacity is reached with 20 active students (10 PhD and 10 Master’s).

**Expected Student Enrollment (Assuming 5-Year Residency for PhD and 2-Year Residency for Master’s)**

<table>
<thead>
<tr>
<th>Year #</th>
<th>No. of Admitted PhD Students</th>
<th>Total Enrolled PhD Students</th>
<th>No. of Admitted Master’s Students</th>
<th>Total Enrolled Master’s Students</th>
<th>Total Enrolled Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Year 2</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Year 3</td>
<td>2</td>
<td>6</td>
<td>5</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>Year 4</td>
<td>2</td>
<td>8</td>
<td>5</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>Year 5</td>
<td>2</td>
<td>10</td>
<td>5</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Year 6</td>
<td>2</td>
<td>10</td>
<td>5</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>

The BMEP is expected to attract students from basic sciences, biomedical sciences, engineering, computer science, and health sciences.

The Program Coordinator with the help of the JPCC will plan and conduct initiatives to advertise the program locally and regionally in order to recruit high quality students while encouraging student diversity. This will include steps such as reaching out to main universities in Lebanon and the Arab World via brochures and visits, coordinating with the University Graduate Council to participate in student recruiting activities and events, developing a website with up-to-date content, seeking support from alumni and members of the BMEP External Advisory Board, and soliciting funds for scholarships to attract and retain distinguished students.
9. EVALUATION

Program evaluation offers a mechanism of providing direction to improve the quality of the program of study, unraveling specific areas of strengths and weakness, and providing baseline data for program improvement. Program evaluation will also provide an assessment of the graduates’ perceptions of the impact of their degree achievement on their professional careers. We plan to continually evaluate the proposed program to guarantee that the needs of students are being met due to the frequently evolving educational environment.

The direct forms of assessment will include evaluation of data collected from courses via embedded exam questions, selected students’ work, and customized design experiments. The indirect form of assessment will include surveys to students and industry, in addition to focus group meetings with various constituents. Other forms of assessment will include career placement of graduating students, publications by graduate students, awards and recognitions, and participation in local and international technical events.

Specific selected core courses required by all students will be used in order to assess all student learning outcomes.

Assessment will also include an account of the student admission policies into the program of study, student enrollment (student demand for the program and number of applicants), credentials of students enrolled in the program (GRE scores, GPA, etc.), standard and performance of students in the program and student academic progress and the distribution of graduate students among the different disciplines of study.

Review process will also evaluate faculty involvement, faculty expertise (research productivity as evidenced by publications and funding and teaching), number of faculty engaged in mentoring graduate students, ongoing research areas and distribution of faculty among the different research disciplines.

The program of study should be reviewed by an external review committee five years after its launch. The reviewers will perform a comprehensive SWOT analysis of the program of study and make recommendations for ways to enhance the effectiveness of the program in achieving its mission and objectives.
**APPENDIX A**

### Layer I – Background Undergraduate Courses: Benchmarking

With the proposed program targeting applicants with diverse backgrounds, efforts were made to ensure that admitted students have the minimum set of core background knowledge and tools that allow them to efficiently commence their graduate-level tenure in the program. This is needed because there is no undergraduate program in biomedical engineering at AUB and, thus, a major subset of admitted students will come from different majors.

The requirements were developed after consulting a set of ABET-accredited top-ranked undergraduate programs in biomedical engineering, including the curricula at Johns Hopkins University, Duke University, and Boston University (see Tables below for summary).

| Johns Hopkins University | Math requirements (6 courses)  
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Computing (1 course)</td>
</tr>
</tbody>
</table>
|                          | Natural Science requirements (4 courses)  
|                          | Two courses in physics with labs  
|                          | Two courses in Chemistry with labs, including Organic chemistry |
|                          | Main Core Knowledge requirements:  
|                          | Molecular Biology (Molecules and Cells)  
|                          | Thermodynamics, statistical Physics (mechanics)  
|                          | Analysis of linear systems (Biological Systems, Signals, and Controls)  
|                          | Biological System Modeling (Ordinary and partial differential equations)  
|                          | Three courses in Systems Bioengineering (Cardiovascular systems, neural, and genetics) |

| Duke University           | Math requirements (6 courses)  
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Calculus I; Calculus II; Multivariable Calculus; linear Algebra and Differential Equations; Statistics.</td>
</tr>
<tr>
<td></td>
<td>Computational (1 course)</td>
</tr>
</tbody>
</table>
|                          | Natural science requirement (4 courses)  
|                          | Two courses in Physics with labs (mechanics; Elect, Magnetism, optics)  
|                          | Two courses in chemistry (core concepts; Modern principles or organic)  |
|                          | Main core knowledge  
|                          | Mechanics of Solids; Structure and Properties of Solids;  
|                          | Two courses in Biology (Molecular; another life science)  
|                          | Quantitative Physiology;  
|                          | Modeling Cellular and Molecular Systems;  
|                          | Fundamentals in Electrical and Computer Engineering;  
|                          | Signals and Systems;  
|                          | Biomedical Electronic Measurements |
Boston University

| Math requirements (6 courses): Calculus 1; Calculus 2; Multivariable Calculus; and Differential Equations; Linear Algebra; Probability. |
| Natural Sciences requirements (4 courses) Two courses in chemistry; Two courses in physics |

Main Core knowledge
- Principles of Molecular Cell Biology and Biotechnology; Introduction to engineering; Electric circuits; Mechanics
- Signals and Systems;
- Thermodynamics and Statistical mechanics;
- solid biomechanics or fluid mechanics;
- Control systems in biomedical engineering;
- Biomedical measurements 1; 2

From these tables, one can find a large degree of uniformity in the basic requirements (ABET type) which include:

- Mathematics: six courses which include three in calculus, one in linear algebra, one in differential equations, and one in probability/statistics.
- Natural sciences: four courses with labs, which include two in physics, and two in chemistry (one in organic chemistry).
- Computing requirement: one course which introduces computational methods and/or programming.
- Main Biology requirements: Molecular and cellular biology; physiology; a biological modeling course.
- Engineering discipline courses: combination of thermodynamics, signals and systems, linear systems control, and mechanics (biomechanics or fluid), and biomedical measurements.

From the above, it is noted that the background undergraduate course requirements of the proposed curriculum adhere to the general core body of knowledge that an undergraduate biomedical engineering student is required to have. The core background knowledge is largely satisfied by the student population at AUB. For applicants with engineering background, most engineering undergraduate programs at AUB are ABET accredited; accordingly, many of the courses listed above are included as part of the curricular requirements for theses disciplines. For applicants from natural sciences disciplines, it is expected that the physics, chemistry and biology course list and parts of the mathematics course list be covered in their undergraduate education; however, they would need to take around one year of background undergraduate engineering courses.
Layer II – Core Graduate Courses: Benchmarking

The second layer in the curriculum design is the most crucial as it includes the set of required core graduate courses in biomedical sciences and engineering. These courses are customized based on the three adopted research focus areas: Biomedical Systems, Biomedical Cybernetics, and Cardiovascular and Pulmonary Engineering.

We have reviewed several biomedical graduate programs while developing the core requirements of curriculum. The exercise revealed salient features of such programs that matched the proposed curriculum in instances where the sampled program is within the three suggested focus areas. The tables below present a brief outline of biomedical engineering doctoral programs in selected universities, namely Johns Hopkins University (JHU), Duke University (DUKE), and University of Pennsylvania (UPenn).

The following is an outline of the course load requirements in the selected example PhD programs:

- In JHU, the course work is composed of a minimum total of 36 credits that are divided into 18 credits of life sciences and 18 credits of elective course work in mathematics/applied mathematics, engineering and/or quantitative biology. The program requires two semesters of teaching assistant experience, a research rotation (1-3 labs) and a general board oral examination.

- In DUKE, the course work involves a minimum total of 36 credits that include as one life science elective, one advanced math elective course, and a maximum of one special reading course. In addition, candidates are required to fulfill two seminar courses (not counted), two semester teaching assistantship and preliminary examination.

- In UPENN, students must complete a total of 9 courses divided into two courses in life sciences (one cellular, one physiology), two courses in Math, three courses in bioengineering fundamentals (analysis, modeling and experimental methods) and two research discipline-specific courses. Students also complete two seminar courses (not counted) and one rotation.

- Other examples: In Columbia University, PhD candidates must complete a total of 42 credits of course work and obtain a Master’s degree. The course load is divided into 24 credits during the Masters and 18 credits during the doctoral tenure. In additions students must complete three semesters of teaching assistantship and pass written and oral qualifying exams.

Based on the above, it is important to note that graduate course work of 30-40 credits is a common requirement for PhD programs. Thus, the requirements of the proposed programs are in line with this, especially that AUB does not offer an undergraduate degree in Biomedical Engineering. In addition, students are required to fulfill a subset of core undergraduate background requirements since they are expected to come from diverse undergraduate programs.
The graduate course topic requirement is dependent on the selected track, area or specialization in any given graduate program. Notwithstanding the wide set of specializations in the programs reviewed, we have attempted to extract a salient set of courses that are required for focus areas that are similar to the designed focus areas in our proposed curriculum. In what follows (tables), we present a brief comparison between core graduate requirements in JHU, DUKE and UPenn doctoral programs and our proposed program. From these tables, one can note common features in the reviewed programs:

- In the life sciences, course requirements included material on cell and molecular biology, signaling and regulation, physiology and genetics.

- In terms of quantitative biology requirements, material included biomaterials, (fluid) mechanics, and computational modeling of biological systems.

- In terms of applied mathematics/engineering core requirements, material included statistics/biostatistics, imaging techniques and/or analysis, linear systems and/or stochastic signal processing, tissue engineering and or polymer science.

Accordingly, we note a good level of correspondence between the core courses in graduate Biomedical Engineering programs at the above universities to the core courses specified in different concentration areas (cybernetics, biomedical, and cardiovascular/pulmonary systems) in the proposed programs.

It comes to no surprise that this comparison is limited to the core requirements and does not extend to other elective type courses since the latter are highly dependent on various tracks as well as the specializations and focus of the involved faculty. Nonetheless, many applied mathematics and advanced engineering courses (such as those listed in the JHU and UPenn programs) are readily available in our engineering departments as part of the current curriculum.

Courses with correlated content in Johns Hopkins and AUB BME

<table>
<thead>
<tr>
<th>Life sciences courses:</th>
<th>Cardiovascular/Pulmonary Physiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systems Bioengineering I (cardiovascular)</td>
<td>Vascular Biology and Inflammation</td>
</tr>
<tr>
<td>Macromolecular Structure and Analysis</td>
<td>Protein Biochemistry</td>
</tr>
<tr>
<td>Genetics Bioinformatics</td>
<td>Nucleic Acids and Basic Genetics</td>
</tr>
<tr>
<td>Pathways and Regulation</td>
<td>Bioinformatics and Proteomics</td>
</tr>
<tr>
<td>Cell Structure and Dynamics</td>
<td>Receptors and Signal Transduction</td>
</tr>
</tbody>
</table>

Quantitative Biology:

<p>| Computational Models of the Cardiac Myocyte | Quantitative Analysis and Modeling of Cardiovascular Systems |
| Models of Neurons, | Computational Modeling of Physiological |</p>
<table>
<thead>
<tr>
<th>Bioelectromagnetic Phenomena</th>
<th>Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiological Fluid Mechanics</td>
<td>Advanced Fluid Mechanics (Rheology)</td>
</tr>
</tbody>
</table>

**Applied Mathematics and Engineering courses with substantial theory content:**

<table>
<thead>
<tr>
<th>Introduction to Statistics</th>
<th>Biostatistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction to Linear Dynamical Systems</td>
<td>Linear System Analysis</td>
</tr>
<tr>
<td>Introduction to Stochastic Processes</td>
<td>Stochastic Processes, Detection and Estimation</td>
</tr>
<tr>
<td>Random Signals</td>
<td>Biomedical Signal and Image processing</td>
</tr>
<tr>
<td>Introduction to Information Theory and Coding</td>
<td>Information Theory</td>
</tr>
<tr>
<td>Nonlinear Systems Theory</td>
<td>Coding Theory</td>
</tr>
<tr>
<td>Learning Theory</td>
<td>Nonlinear Systems</td>
</tr>
<tr>
<td>Artificial Intelligence for Control</td>
<td>System Identification</td>
</tr>
</tbody>
</table>

Courses with correlated content in Duke University and AUB BME

**Life Science Electives:**

<table>
<thead>
<tr>
<th>Cell and Developmental Biology</th>
<th>Cell and Tissue Biology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular Signaling</td>
<td>Cell Signaling in Health and Disease</td>
</tr>
<tr>
<td>Introductory Biochemistry I,II</td>
<td>Receptors and Signal Transduction</td>
</tr>
<tr>
<td>Introduction to Physiology</td>
<td>Nucleic Acids and Basic Genetics; Protein Biochemistry</td>
</tr>
<tr>
<td>Human Genetics</td>
<td>Quantitative Physiology</td>
</tr>
<tr>
<td>Gene Regulation</td>
<td>Bioinformatics and Proteomics</td>
</tr>
</tbody>
</table>

**Advanced Math Courses:**

<table>
<thead>
<tr>
<th>Statistics for Basic Biomedical Scientists</th>
<th>Biostatistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematical Modeling</td>
<td>Linear System Analysis</td>
</tr>
<tr>
<td>Computational Fluid Mechanics and Heat Transfer</td>
<td>System Identification</td>
</tr>
<tr>
<td>Advanced Fluid Mechanics</td>
<td>Advanced Fluid Mechanics</td>
</tr>
<tr>
<td>Heat and Mass transfer (undergrad)</td>
<td>Heat and Mass transfer (undergrad)</td>
</tr>
</tbody>
</table>

**BE courses:**

<table>
<thead>
<tr>
<th>Modern Diagnostic Imaging Systems</th>
<th>Biomedical Diagnostic Imaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computational Methods in Biomedical Engineering</td>
<td>Computational Modeling of Physiological Systems</td>
</tr>
<tr>
<td>Theoretical and Applied Polymer Science</td>
<td>Polymer Science</td>
</tr>
<tr>
<td>Fundamentals of Biomaterials and Biomechanics</td>
<td>Biomechanics (?)</td>
</tr>
<tr>
<td>Tissue Biomechanics</td>
<td>Tissue Engineering and Biomaterials</td>
</tr>
<tr>
<td>Tissue Engineering</td>
<td>Advanced Fluid Mechanics (Rheology)</td>
</tr>
<tr>
<td>--------------------</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td>Introduction to Biofluid Mechanics</td>
<td>Advanced Fluid Mechanics (Rheology)</td>
</tr>
</tbody>
</table>

Courses with correlated content in Upenn and AUB BME

**Biological Sciences:**
- Cell Biology
- Bioinorganic Chemistry
- Molecular Biophysics I
- Macromolecular Biophysics II
- Mass Spectrometry and Proteomics
- Introduction to Anatomy and Physiology
- Genetic Principles
- Principles of Cardiovascular Biology
- Advanced Seminar in Cell Death and Survival
- Human Physiology

<table>
<thead>
<tr>
<th>Cell and Tissue Biology</th>
<th>Protein Biochemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell Physiology and Biophysics</td>
<td>Bioinformatics and Proteomics</td>
</tr>
<tr>
<td>Quantitative physiology</td>
<td>Vascular Biology and Inflammation</td>
</tr>
<tr>
<td>Cell Signaling in Health and Disease</td>
<td>Nucleic Acids and Basic Genetics</td>
</tr>
<tr>
<td>Cardiovascular Physiology</td>
<td>Seminars and Journal Clubs</td>
</tr>
<tr>
<td>Organ Physiology</td>
<td></td>
</tr>
</tbody>
</table>

**BE fundamentals:**
- Bioengineering III: Biomaterials
- Principles, Methods, and Applications of Tissue Engineering
- Biomedical Image Analysis
- Fundamental Techniques of Imaging I, II
- Fundamentals of Magnetic Resonance
- Polymers and Biomaterials
- BioTransport: Fluid Mechanics, Heat and Mass Transfer
- Mathematical and Computational Modeling of Biological Systems

<table>
<thead>
<tr>
<th>Tissue Engineering and Biomaterials</th>
<th>Biomedical Signal and Image Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomedical Diagnostic Imaging</td>
<td>Biomedical Engineering I, II</td>
</tr>
<tr>
<td>Biomedical Signal Analysis Lab (1 Cr)</td>
<td>Polymer Science</td>
</tr>
<tr>
<td>Heat and Mass transfer (undergrad)</td>
<td>Computational Modeling of Physiological Systems</td>
</tr>
<tr>
<td>Mathematics Courses:</td>
<td>Biostatistics</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Concepts and Methods in Biostatistics – Basic</td>
<td></td>
</tr>
<tr>
<td>Concepts and Methods in Biostatistics - Intermediate</td>
<td></td>
</tr>
<tr>
<td>Mathematics of Medical Imaging and Measurements</td>
<td></td>
</tr>
<tr>
<td>Introduction to Linear Models and Generalized Linear Models</td>
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</tr>
<tr>
<td>Control of Nonlinear Systems</td>
<td></td>
</tr>
<tr>
<td>Linear Systems Theory</td>
<td></td>
</tr>
<tr>
<td>Digital Signal Processing</td>
<td></td>
</tr>
<tr>
<td>Random Process Models and Optimum Filtering</td>
<td></td>
</tr>
<tr>
<td>Information Theory</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biomedical Signal and Image Processing</td>
</tr>
<tr>
<td></td>
<td>Biomedical Engineering I</td>
</tr>
<tr>
<td></td>
<td>System Identification</td>
</tr>
<tr>
<td></td>
<td>Nonlinear Systems</td>
</tr>
<tr>
<td></td>
<td>Linear System Analysis</td>
</tr>
<tr>
<td></td>
<td>Stochastic Processes, detection and Estimation</td>
</tr>
<tr>
<td></td>
<td>Information Theory</td>
</tr>
</tbody>
</table>

**John Hopkins**
- Cell and tissue engineering
- Cardiovascular systems
- Medical imaging
- Systems neuroscience
- Molecular and cell systems
- Bioinformatics and computational biology
- Computational modeling

**Case Western**
- Biomaterials, Drug Delivery and Tissue Engineering
- Biomedical Imaging
- Neural Engineering and Rehabilitation
- Biomedical Sensors
- Metabolic Systems
- Cardiac and Vascular Systems
- Musculoskeletal Mechanics

**UCLA**
- Biomedical Signal, Image Processing
- Biomedical Instrumentation
- Biomaterials, Tissue Engineering, and Biomechanics
- Medical Imaging Informatics
- Molecular & Cellular Boeng’g
- Biosystem Science and Eng’g
- Neuroengineering

**Columbia**
- Cell and tissue engineering
- Biomechanics
- Biomedical imaging