PROPOSAL FOR NEW MASTERS PROGRAM

University of Louisville
Institution Submitting Proposal

MS Bioengineering
Degree Designation as on Diploma

Master's of Science in Bioengineering
Title of Proposed Degree Program

EEO Status	_____
CIP Code	_____
Academic Unit (e.g. Department, Division, School)	Bioengineering Department, JB Speed School of Engineering
Name of Academic Unit	School of Engineering
Name of Program Directors	Gina Bertocci, PhD, PE; Ayman El Baz, PhD
Intended Date of Implementation	Fall ~~2018~~2019
Anticipated Date for Granting First Degrees	Fall ~~2019~~2020
Date of Governing Board Approval	_____
Name, Title and Information of Contact Person	Gina Bertocci, PhD, PE Professor, Bioengineering g.bertocci@louisville.edu 502.852.0296

Date of CPE Approval _____

Evaluation Criteria

All actions in the approval of new programs for public institutions are subject to a stipulation regarding the program's ability to attain specified goals that have been established by the institution and approved by the Council on Postsecondary Education (the Council). At the conclusion of an appropriate period of time, the program's performance shall be reviewed by Council staff following criteria established in the Council's Academic Programs Policy.

A. Centrality to the Institution's Mission and Consistency with State's Goals

As part of former Governor Paul Patton's higher education initiative in 1998, the University of Louisville began the *Challenge for Excellence* to expand and enhance research in order to "become a premier, nationally-recognized metropolitan research university." In addition, local businesses commissioned consultants to recommend the means to improve competitiveness and they found that the local infrastructure is in place for Louisville to be competitive in the biomedical and biotechnology industries. In response to these initiatives, the University of Louisville, and in particular the Speed School of Engineering and the School of Medicine, has made bioengineering a top priority and has demonstrated its commitment to developing a nationally recognized bioengineering program and to provide a formal structure for educating students in bioengineering and attracting faculty with the ability to establish multidisciplinary research programs.

The proposed Master's of Science in Bioengineering (MS in Bioengineering) represents an endeavor at the University of Louisville (U of L) to create a degree enabling non-U of L graduates with Bachelor's degrees in engineering to enroll in a Master's degree program in the Department of Bioengineering. Currently the Department of Bioengineering offers an ABET accredited Master's of Engineering (MEng) degree which limits enrolled only to those students having a Bachelor's degree in Bioengineering from U of L given accreditation stipulations. Thus, Bioengineering faculty are proposing a MS in Bioengineering to fulfill the on-going demand of graduates from schools other than U of L. Building upon our existing degree programs and expertise of our faculty, we are positioned to provide coursework and training needed for a MS in Bioengineering.

This degree will offer advanced level training to provide students with in-depth knowledge of bioengineering in areas such as biocomputational modeling, bioimaging, bioinstrumentation, biomaterials, biomechanics, biomedical devices, bioMEMS, bionanotechnology, biosensors, biosignal processing, biosystems control, molecular bioengineering, and tissue engineering. Student educational experiences will be enhanced by research opportunities in laboratories conducting basic and translational research on oncology, cardiovascular disease, nanotherapeutics, orthopedics, drug delivery, injury, tissue regeneration and image-based diagnostics. Employment of bioengineers is projected to grow 23 percent from 2014 to 2024 – 3 times the average for other occupations. The MS in Bioengineering will prepare students for career tracks in industry or governmental agencies, and will also provide a strong foundation for those wishing to pursue doctoral studies.

1. **List the objectives of the proposed program. These objectives should deal with the specific institutional and societal needs that this program will address.**
   The proposed Master of Science in Bioengineering degree program objectives are to:

   1. Train highly motivated graduate students who demonstrate advanced level bioengineering expertise and practical engineering experience necessary to function as bioengineering professionals. *(Advanced Knowledge and Life-long Learning)*
   2. Develop students with the bioengineering expertise and practical experience necessary for employment in industry, academia or government, or further professional/graduate studies. *(Career Opportunities)*
   3. Develop students with an understanding of the broad, social, ethical and professional issues of contemporary engineering practice. *(Awareness and Responsibility)*

   Bioengineering is a relatively new engineering discipline when compared to the long-standing traditions of other fields of engineering. A bioengineer uses traditional engineering skills and tools to analyze and solve problems in biology and medicine. Bioengineers collaborate with physicians, biologists, biochemists, chemists, clinicians, dentists, physiologists, therapists, and virologists to design, develop and manufacture instruments, devices, materials, prophylactics, software, and therapeutics, or to develop new procedures to solve clinical problems. Bioengineers also are trained to objectively evaluate the efficacy of therapeutic interventions intended to advance healthcare and/or improve quality of life. The aging of the population and focus on health issues will increase the demand for improved medical devices, equipment and therapeutics designed by bioengineers working on interdisciplinary teams. In 2012, the President's Council of Advisors on Science and Technology – an advisory group of the nation's leading scientists and engineers – set forth a goal, based on economic forecasts, to produce one million additional graduates with degrees in science, technology, engineering and mathematics. Employment opportunities for bioengineers are predicted to continue growing faster than the average for all occupations through 2020 as reported by CNNMoney[1] with a 10-year job growth of ~62%. Combined with a growing job market and attractive compensation (median pay: $87,000[1]), bioengineers have the gratification that comes from working to meet the needs of society and improve quality of life. Bioengineers choose their field to be of service to people and to apply engineering knowledge and skills to complex biological systems and healthcare challenges.

   With regards to societal impact, premature death rate is a surrogate indicator for overall health status, with high rates suggestive of decreased work productivity and economic development. Unfortunately, the premature death rate in Kentucky exceeds the national average.[2] Closer evaluation reveals that Kentucky has a higher incidence of cancer, heart disease, diabetes, high blood pressure, asthma, disabilities and edentulism than most states.[3] Cancer, cardiovascular disease and respiratory illness are often consequences of tobacco use. More than half of individuals who smoke will die of a smoking-related illness. Coincidentally, 23% of all deaths in Kentucky can

1 http://money.cnn.com/gallery/pf/jobs/2013/11/13/fastest-growing-jobs/
2 State Health Assessment, KY Dept. for Public Health, 2013
3 The Health of KY, KY Institute of Medicine, 2007

be attributed to smoking. Death rates associated with lung, colorectal, prostate and breast cancer in Kentucky greatly exceed national averages. Another major health challenge facing Kentuckians is obesity, which leads to an increased incidence of cardiovascular disease, diabetes, stroke and other health disorders. Violence-related fatalities also plague our Commonwealth, with Kentucky having the dubious distinction of one of the highest rates of child maltreatment, exceeded only by New York and the District of Columbia. Accidental injuries, such as those resulting from motor vehicle crashes, are also a leading cause of death in Kentucky. Advancing the health status and providing safe environments for Kentuckians is key to improving the productivity and economic viability of our Commonwealth. Advanced level bioengineers, working in collaboration with clinical scientists and clinicians, are uniquely positioned to influence change through the development and translation of early diagnostic and interventional biomedical devices and technologies. Additionally, through the application of advanced engineering principles and techniques, bioengineers work in multidisciplinary teams towards the discovery of underlying disease etiologies allowing for the development of therapeutic strategies to limit or mitigate morbidity and improve quality of life. Currently U of L bioengineering faculty, students and trainees are collaborating with their clinical counterparts to address many of these daunting health-related problems (e.g. cancer, child maltreatment, cardiovascular disease, disabilities, diabetes, motor vehicle related injuries) challenging Kentuckians. However, creating a sustainable positive impact on the health and well being of Kentuckians is dependent upon effective capacity building in the field of bioengineering. The proposed MS in Bioengineering program presents an opportunity to reach a new student population and increase our training of students to become advanced-level bioengineers who will have the capabilities to influence the health and quality of life of Kentuckians and those living with similar morbidities. Students matriculating from this program will have a unique skill set with capabilities to design, develop and translate potential solutions and technologies to advance the health status of Kentuckians, thereby aiding our Commonwealth in realizing improved productivity and economic gains.

2. Explain how the proposed program relates to the institutional mission and strategic plan.

Establishing a MS in Bioengineering will address a number of goals of the University's Strategic 2020 Plan and the 21st Century Initiative. Specifically, as related to the relevant goals stated in these initiatives, the MS in Bioengineering will:

<u>2020 Plan</u>

1. Implement STEM initiatives leading to more graduates with science, technology, engineering and mathematics majors…
2. Increase the quality and quantity of graduates in the health sciences to improve the health care of the population
3. Increase the emphasis on clinical research and translational science that can be commercialized

<u>21st Century Initiative</u>

1. Revenue Enhancement: "Strategically grow enrollment in high demand fields".

In addition to these university-wide goals, this degree will also address several goals outlined the JB Speed School of Engineering 2020 Strategic Plan:

1. Establish areas of research excellence in engineering human health
2. Attract motivated, prepared and talented students into all degree programs
3. Provide outstanding experiential learning experiences

3. Explain how the proposed program addresses the state's postsecondary education strategic agenda.

The MS in Bioengineering is in alignment with the State of Kentucky's *Stronger by Degrees: 2016-2021*[4] post-secondary education strategic agenda. A major goal of this plan is to raise Kentucky's educational attainment level to 58% by 2025, up from its current level of 45%. CPE's post-secondary education goals include "improving the readiness of employability of post-secondary education graduates" and to "advance Kentucky's STEM and health agendas…". The MS in Bioengineering aligns with this agenda by providing a mechanism to enable Kentuckians to succeed in a global economy (Vision), delivering a world-class education to our students through the creation and application of new knowledge, and growing the economy of the Commonwealth (Mission). Moreover, the proposed degree program will prepare students for career paths in STEM and health-related fields. Many STEM and health-related jobs have relatively high salaries; CPE recognizes that "highly educated people create additional savings from lower costs in health, unemployment, public assistance and crime." Graduates from the MS in Bioengineering who stay in Kentucky will also help to improve patient outcomes and quality of life, especially in clinical areas of high importance to Kentucky, in particular, cardiovascular, cancer, disability and neurosciences. Consistent with the vision of Robert King, President, Council on Post-Secondary Education, this program will lead to graduates who will improve the human condition and strengthen Kentucky's economy.

The proposed program fulfills the *Research, Economic, and Community Development* criteria - Kentucky will be stronger by generating new knowledge, producing high-demand degrees, increasing the educational attainment of its workforce, and improving its communities. This program will increase educational attainment and quality of life in Kentucky communities through regional stewardship[2] (Strategic Policy Objective 8). Additionally, by addressing the need for Efficiency and Innovation, Kentucky will be stronger by creating new ways of serving more postsecondary students at a high quality in a challenging resource environment by increasing academic productivity through innovation[2] (Strategic Policy Objective 9) and maximizing postsecondary and adult education resources[2] (Strategic Policy Objective 10).

4. Explain how the proposed program furthers the statewide implementation plan.

The statewide implementation plan has now been incorporated into a subsection of the newly established *Stronger by Degrees: 2016-2021*. The implementation plan promotes a legislative agenda, which supports post-secondary education through various funding initiatives, including a new Outcome-Based Funding Plan. U of L's Strategic Plan must address these outcome-based

4 http://cpe.ky.gov/NR/rdonlyres/0BA94290-AAF3-452D-AB5F-5F0EF73523C7/0/strategicagendafaqs.pdf

metrics once they are finalized. Our proposed MS in Bioengineering aligns with goals of the U of L Strategic Plan, as well as the *Stronger by Degrees* plan (see items 2 and 3 above).

The Bioengineering Department has a proven track record of *Accountability* in higher education as demonstrated by ABET accreditation of the BS and MEng degrees (July 1, 2013); the only jointly accredited program in the nation, which was achieved using well-defined *Performance Metrics and Targets*, an *Implementation Plan*, and annual *Reporting and Benchmarking*.

Our engineering faculty have demonstrated a nationally and internationally-recognized level of research productivity as evidenced by quality and placement of our graduate BS and MEng students, presentations at national and international conferences, publications in high-impact peer refereed journals, and extramural funding. The success of existing faculty will enable the delivery of high quality educational and research opportunities for students pursuing the thesis option, and will lead to graduates capable of translating their knowledge to address the clinical needs of Kentuckians and society. In summary, the proposed MS in Bioengineering at the University of Louisville will exceed the requirements of our State's Strategic Agenda.

B. Program Quality and Student Success

The curriculum should be structured to meet the stated objectives and student learning outcomes of the program.

1. List all student learning outcomes of the program

a) demonstrated advanced level of bioengineering knowledge
b) an understanding of the clinical relevance bioengineering topics
c) an understanding of contemporary bioengineering topics
d) ability to effectively communicate advanced knowledge of bioengineering orally and in writing

2. Explain how the curriculum achieves the program-level student learning outcomes by describing the relationship between the overall curriculum or the major curricular components and the program objectives.

This degree will offer advanced level training to provide students with in-depth knowledge of Anatomy/Physiology, Bioinstrumentation and Advanced Engineering Mathematics, along with specialized training in Molecular and Tissue Engineering, Bioimaging and Biocomputational, Bioelectrical and Biomedical Devices, and/or Biomechanics and Rehabilitation. Bioengineering Seminar series will expose students to a wide range of contemporary topics within the field of bioengineering, and will aid students in identifying areas of interest. Student educational experiences will be enhanced by research opportunities in laboratories conducting basic and translational research in the areas of oncology, cardiovascular disease, nanotherapeutics, orthopedics, rehabilitation, drug delivery, injury, tissue regeneration and image-based diagnostics. Students matriculating from this program will have a unique skill set with capabilities to design, develop and translate potential bioengineering solutions and technologies that will advance health and quality of life.

Through their thesis research or biomedical project students will demonstrate their ability to achieve the Student Learning Outcomes listed above. Student progress will be recorded and reviewed by the Bioengineering faculty each year.

3. Highlight any distinctive qualities of this proposed program.

There is a strong bioengineering community at the University of Louisville; this community is built upon established collaborations between Bioengineering Department faculty and faculty in the Schools of Medicine and Dentistry, along with faculty in other departments within the Speed School of Engineering. These multidisciplinary collaborations have led to extensive federal and private foundation research funding targeting the development of bioengineering solutions to improve patient outcomes and quality of life. An example of such programs includes the Wallace H. Coulter Foundation Translational Partnership award to the U of L Department of Bioengineering in collaboration with the U of L School of Medicine and Office of Technology Transfer for the purposes of establishing a translational research program. This prestigious award placed the University of Louisville in the "Sweet 16" of US Institutions in the area of Translational Research. The proposed MS in Bioengineering will leverage the Coulter Translational Partnership Award to accelerate the development and growth of clinical translational research at the University of Louisville. The mission of the Coulter Translational Partnership at the University of Louisville is to promote medical innovation by establishing critical collaborations between engineers and clinicians to address significant unmet clinical needs, particularly in the areas of diagnostics and therapeutics.

The extensive bioengineering community at U of L will provide a rich multidisciplinary training environment for students in the proposed program, enabling them to receive extraordinary hands-on experience in laboratories directed by Bioengineering faculty. Students in the program will have a unique opportunity to conduct their research while functioning on multidisciplinary teams that are based upon established engineer-clinician collaborations and an associated track record of successful development and translation of medical innovations.

4. Will this program replace or enhance any existing program(s) or concentration(s) within an existing program?

This program will not replace any existing programs. The program will enable graduates with non-U of L ABET-accredited engineering degrees to pursue a MS in Bioengineering at U of L. This program will also serve as a potential feeder to our existing U of L Doctor of Philosophy in Interdisciplinary Studies: Specialization in Translational Bioengineering (ISSTBE) program.

5. Is there a specialized accrediting agency related to this program?

a. If yes, identify the agency.

Accreditation Board for Engineering and Technology (ABET)

b. Do you plan to seek accreditation?

No

c. If yes, explain your plans for accreditation. If no, explain your rationale for not seeking accreditation.

Speed School of Engineering has been awarded dual accreditation of BS and MEng degrees in each engineering discipline, including BE. None of the existing MS degrees are ABET accredited in Speed School since accreditation is not required for licensure or to meet other professional standards. Few MS in engineering degrees are ABET accredited in the US. Additionally, our current MEng degree is accredited as a 5-year program, requiring that students complete their BS degree in the same engineering discipline at U of L so that tight management of incoming academic competencies can be achieved. Since students entering the MS BE program will have BS degrees from non-U of L schools and can enter with a BS in engineering disciplines other than BE, we will not be able to assure similar control over incoming academic background that is necessary for accreditation. Given these reasons, accreditation of the MS BE degree program will not be pursued and is unnecessary.

6. **Attach the SACS Faculty Roster Form. Faculty resources shall be demonstrated to be adequate and appropriate for the proposed program. The number of faculty should meet external standards where appropriate. The qualifications of faculty will support the objectives and curriculum of the proposed program.**

The SACS Faculty Roster Form is attached in Appendix A.

7. **Access to the qualitative and quantitative library resources must be appropriate for the proposed program and should meet recognized standards for study at a particular level or in a particular field where such standards are available. Adequacy of electronic access, library facilities, and human resources to service the proposed program in terms of students and faculty will be considered. Physical facilities and instructional equipment must be adequate to support a high quality program. The proposal must address the availability of classroom, laboratory, and office space as well as any equipment needs.**

a. Describe the library resources available to support this program. You may attach any documentation provided to SACS.

This program will be supported by the Ekstrom (Main) and Kornhauser Libraries which house over 2.1 million volumes, approximately 16,000 current journal subscriptions, special collections, media and microforms. In addition, the library has an on-line virtual library that provides faculty, staff and students access to over 20,000 full text electronic journals, inter-library loan services, electronic books and databases, reference materials and other library resources. The library resources are more than adequate to support the needs of the faculty and students in the proposed MS program.

A letter from the Dean, University Libraries is included in Appendix B, indicating that the University's collection of journals, electronic resources and special collections is adequate to support the MS in Bioengineering program.

b. Describe the physical facilities and instructional equipment available to support this program.

Offices - The Bioengineering Department is located on the University of Louisville Belknap campus in Lutz Hall, which contains the department office, two teaching classrooms, two instructional laboratories, a conference room, and faculty research laboratories. Offices for faculty and staff are located in buildings across the Belknap Campus (Lutz Hall and Shumaker Research Building) and Health Sciences Campus (Cardiovascular Innovation Institute, Clinical Translation Research Building and Health Sciences Research Tower). Offices for faculty and staff in the School of Business are located in Harry Frazier Hall on the Belknap campus. In addition, department and faculty offices for other Speed School of Engineering departments are located in Ernst Hall (Chemical Engineering), Duthie Center (Computer Engineering & Computer Science), J.B. Speed Building (Industrial Engineering), Sackett Hall (Mechanical Engineering), W.S. Speed Building (Electrical & Computer Engineering). Offices for faculty and staff on the Health Sciences Campus are located in Building A Research Tower (Biochemistry & Molecular Biology; Microbiology & Immunology; Physiology & Biophysics), Medical & Dental Research Building (Anatomical Sciences & Neurobiology) and School of Dentistry.

Classrooms and Instructional Laboratories – The proposed bioengineering-specific courses are offered primarily in Lutz Hall, but the additional program courses are offered in classrooms across both the Belknap and Health Sciences Campuses including Duthie Center, Ernst Hall, HSC A Building, and J.B. Speed Building for delivery of the proposed curriculum. All classrooms have adequate lighting, climate control and acoustic characteristics, and are equipped with computers that interface with overhead LCD projectors. All buildings on the Belknap and Health Sciences Campuses are equipped with wireless internet access.

Computing Resources - The University of Louisville central research computing or Cardinal Research Cluster (CRC) is housed in the UofL Information Technology Data Center located in the Miller IT Center on the university's Belknap campus. This facility provides over 5000 square feet of secure, environmentally controlled data center space including a FM200 fire suppression system. The data center is fed by 1000kVA electrical service with backup power provided by a large UPS and an 1125 kVA diesel generator. The research cluster is equipped with its own dedicated in-row cooling systems, and utilizes cold aisle containment to improve cooling efficiency. The facility is physically secure with limited keycard access and is monitored 24 hours a day. The UofL CRC infrastructure became available in spring 2009 and was upgraded in spring 2011. This infrastructure includes multiple systems serving the

research needs of the entire university, including a general-purpose high-performance distributed-memory computation cluster, a high-memory SMP system and several general-purpose web and software servers. The general-purpose compute cluster is composed of 312 IBM iDatplex nodes each equipped with two Intel Xeon L5420 2.5 GHz quad-core processors for a total of 2496 processor cores. Each node has 16 or 32 GB of memory, and the node interconnects are a mixture of Gigabit Ethernet (1Gbps) and InfiniBand (16 Gbps) technology. The cluster is estimated to have a peak performance rating of 20+ TFLOPS. The University of Louisville's campuses are served by a 40 Gigabit per second (Gpbs) campus backbone network. This backbone is comprised of over 80 miles of fiber in a dual ring configuration. The wired network can provide 100Mbps and 1Gbps Ethernet service for faculty and staff communications needs. With the recently completed Pervasive Wireless Project, the U of L campus wireless network provides 802.11n wireless connectivity to wireless devices at speeds up to 300Mbps. This wireless connectivity is available across all of U of L's campuses, classrooms and buildings. The University of Louisville is connected to the Internet2 node via dedicated 10Gbps optical fiber backbone network. The Internet2
connection gives the University of Louisville direct, high bandwidth, access to national research and education networks such as XSEDE/Teragrid. The University of Louisville is also a member of the Kentucky Regional Optical Network (KyRON). This regional optical network is managed and operated through a consortium including the University of Louisville, the University of Kentucky and the Kentucky Council on Postsecondary Education. Participating universities are interconnected using 10Gbps optical links. The Kentucky RON extends the research data sharing capabilities of the University of Louisville with other participating universities throughout the state, and provides new opportunities for collaboration.

Multi-Disciplinary & Core Research Facilities - To support the training of students in state-of-the-art research methodologies and techniques, MS BE students will have access to a number of multidisciplinary and core research facilities (described below), as well as to individual faculty laboratories. Specifically, students will have access to the multi-disciplinary facilities described below:

BIOINFORMATICS LABORATORY is housed in the CECS department in room 238 of the Duthie Center. The facilities include a: visualization wall consisting of an assembly of 3x6 Dell monitors and used to visualize complex images; video conferencing system; powerful computers including Dell precision T7400 (8 processors, 20 gb RAM, 2 TB HDD, NVIDIA card) and Dell Alienware computers (8 processors, 12 GB RAM, 1 TB HDD, NVIDIA card); library with bioinformatics and related fields books; and, panaboard (Panasonic White board) that can take pictures of the discussion and can be saved and printed from computer.

CONN CENTER MATERIALS CHARACTERIZATION FACILITY is equipped with Electron Microscopy including High Resolution FEG-TEM/STEM, High Resolution FEG-SEM,

and Analytical SEM. The instruments in the Conn Center Materials Characterization Facility include a 200UkV field-emission FEI Tecnai F20 TEM, a field-emission FEI Nova600 SEM, and an analytical JEOL JMS5010 SEM. TEM accessories consist of Gatan GIF2002 and EDAX spectrometers, a Fishione HAADF detector, and various sample holders (3UD tomography, cooling, heating, etc.). The system is capable of high-resolution (HRTEM), energy-filtered (EFTEM) and Z-contrast (STEM) imaging, diffraction (SAED, CBED, nanodiffraction), analytical and spectroscopic studies (EELS, EDX, chemical tomography) at nanoscale, as well as, in situ heating (up to 1100° C) and cooling (down to LN2 temperature) experiments. The imaging point resolution of 0.24 nm and spectroscopic energy resolution of 0.8eV can be obtained with this system.

THE UNIVERSITY OF LOUISVILLE MICRO/NANOTECHNOLOGY CENTER occupies approximately 12,000 sq ft and includes laboratories focused on the development of MEMS/NEMS-based devices using: 1) Computer-aided design; 2) testing and packaging; 3) microfabrication cleanroom; and, 4) micromechanical machining. The UofL Micro/NanoTechnology Center conducts and facilitates R&D on MEMS/NEMS-based technologies including those with high commercialization potential. The Center promotes partnerships among the state's colleges and universities, private industries, and non-profit organizations to actively pursue federally and privately funded research and development resources that are dedicated to MEMS/NEMS solutions

MICRO/NANOTECHNOLOGY CLEANROOM FACILITY. The Micro/ NanoTechnology Cleanroom (MNTC) is a $30M class 100/1000 cleanroom facility established to support a wide range of research and academic initiatives in the growing areas of micro/nanotechnology, advanced materials, biotechnology, MEMS at the University of Louisville and throughout the state of Kentucky. This 10,000 ft2 Abbie Gregg, Inc. designed cleanroom opened in the Summer of 2006 and is located on the 1st floor of the new $60M Shumaker Research Building. The cleanroom is strategically divided into 7 bays – two for photolithograghy and mask generation, one for wet processing (etching/cleaning/plating), one for dry etching, one for thin film deposition, one for high temperature processing, and one for PDMS processing. The Micro/NanoTechnology Core Facility is utilized for the fabrication of MEMS (microelectromechanical) devices and structures, bioMEMS devices, nanoUscale devices and structures, microelectronic devices, and electroUoptic devices. It is utilized by a wide variety of disciplines, including ECE, ME, BE, ChE, Chemistry, Physics and Medicine. Due to stringent processing requirements, the lab is designed to meet class 1000 cleanroom specifications within five of the processing bays and class 100 specifications in its two lithography bays. Activities performed in the MNTC Cleanroom include: photolithography with back side alignment, eUbeam lithography, oxidation, thermal diffusion and annealing, rapid thermal processing, thermal and electron beam evaporation, plasma enhanced chemical vapor deposition (PECVD), Molecular Vapor Deposition (MVD), Atomic Layer Deposition

(ALD), RF/DC sputtering, spinning, parylene deposition, RCA substrate cleaning, anisotropic and isotropic dry and wet etching, XeF2 isotropic dry etching reactive ion etching (RIE), deep reactive ion etching (DRIE), bulk micromachining, anodic bonding with wafer bond alignment, silicon fusion bonding (SFB), low temperature glass bonding, electroplating, photomask generation with greyscale capabilities, maskless lithography or direct write, wirebonding, metrology and material characterization.

MEMS COMPUTERMAIDED DESIGN LABORATORY includes four high end workstations located in the Belknap Research Building are dedicated to running CoventorWare© a MEMS finite element modeling software which has modules for simulation of mechanical, electrical, thermal, and fluidic phenomenon in the micro regime. Both preUprocessing (model design and generation) and postUprocessing (simulation and data extraction) is accomplished on the workstations. The workstations are also equipped with LUEDIT, Athena and TUSpice software for MEMS layout generation, semiconductor fabrication process simulation and circuit modeling, respectively. In addition, the licensing configuration for the software effectively allows anyone on campus to run the software, which is particularly advantageous for inspecting results at locations away from the more powerful systems.

MEMS TESTING & PACKAGING LABORATORY is a 1200 sq. ft. laboratory for the packaging and testing of MEMS devices fabricated in the Micro/Nanotechnology Facility. The lab includes two fume hoods and a full complement of utilities, including DI water. This research and instructional facility contains numerous backend and postUprocessing pieces of equipment appropriate for the packaging and assembly of MEMS and microelectronic devices. Additionally it contains many electronic instruments for device testing and characterization.

MICROMECHANICAL MACHINING LABORATORY is dedicated to the development of micro mechanical machining methodologies to produce MEMSUbased devices fabricated out of nonUsilicon materials as well as silicon. The lab includes a full complement of utilities including nitrogen, air, water, a sink, and electrical outlets. This facility contains multiple pieces micromechanical machining equipment.

HUSON NANOTECHNOLOGY CORE FACILITY. This analytical imaging facility was established in 1998 with the partial support of an NSF MRI grant. It is housed in the new Belknap Research Building which opened in December 2005 and consists of ~1800 sq. ft. of space which contains microscopes that can measure the three-dimensional shapes of ultrasmall objects with precision up to 5000X finer than that of conventional light microscopes. The Three-Dimensional Nanoscale Imaging Facility features several complementary instruments that can measure three-dimensional topography and other related physical properties of nanoscale and atomic surfaces. These instruments are the first of their kind at a Kentucky university or business. All instruments are PC controlled and attached via TCP/IP to a local

Microsoft Windows NT domain, and the university's main network. The 3D Nanoscale Imaging Facility is actively used by various research groups for diverse projects that require ultra-precise three-dimensional profiling, and even nanoscale-sculpting of small surfaces.

RAPID PROTOTYPING CENTER. The University of Louisville (UofL) has one of the best-equipped facilities with world class capabilities for 3D Printing/Additive Manufacturing (AM) of metals and polymers. The industrial/academic consortium known as the Rapid Prototyping Center (RPC) has been performing federally-funded basic and applied research, technology transfer and industry-funded projects in AM since starting with polymer Laser Sintering (LS) in 1993. Today the UofL has over 20 people focused on AM applications and research. The UofL is a partner of leading AM users such as Boeing, GE, EWI, Nike, Emerson, Northrop-Grumman, Burton, Integra, and several service bureaus. There are over 70 industrial/academic consortium member organizations in the Rapid Prototyping Center. The University of Louisville Rapid Prototyping Center (RPC) was formed in 1993 as a consortium between the university and five local companies to investigate the new technology of rapid prototyping via laser sintering and its impact on the design cycle. Today the RPC's 70+ members have access to world-leading capabilities in Additive Manufacturing (AM) via laser and electron beam powder bed processes for metals, plastics, and ceramics; ultrasonic additive sheet lamination; plus many ancillary processes and techniques. The assistance available to joint academic/industrial consortium partners has grown from helping companies to understand rapid prototyping to aiding members in the entire product development process: conceptual design, material selection, prototyping, tooling, production, applied and basic research. The RPC has the latest software for solid modeling and part design of new components and the capability for reverse engineering of existing parts. The RPC combines the expertise of its professional staff and faculty with strategic partnerships to assist in all aspects of product and process development. The RPC supports research and development programs in Additive Manufacturing and provides student instruction in the application of these new technologies. The role of technology transfer and new business development is fueled by interaction with the industrial consortium members and emphasizes the utilization of University resources to enhance job growth. Users gain access to the problem-solving technology as well as continuing research in Additive Manufacturing. Benefits also include access to UofL's Speed School of Engineering graduates engineers of the future with training in this state of the art technology. The University of Louisville Rapid Prototyping Center (RPC) is capable of producing prototypes and end use, low volume component parts utilizing the following additive manufacturing systems: Laser Sintering (LS), Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM), Ultrasonic Consolidation (UC), Fused Deposition Modeling (FDM), and Stereolithography (SLA). The RPC has become an industry leader in Additive Manufacturing applications with expertise and funded research in all areas of Additive Manufacturing. This includes the fundamental understanding of the effect

of process variables and properties, material development, design for AM, and testing. AM research areas include the following: 1) Laser Sintering of Polymers U Process control and optimization; Mechanical properties; Hardware improvements; Materials research and development; and, High temperature materials; 2) Additive Metals Processing U Evaluation of process variable on mechanical properties; High performance alloys; and, Post processing parameters e.g. – annealing or heat treating; 3) Advanced Additive Manufacturing Techniques; Multi-material and gradient structures; Embedded electronics; Controllable microstructures; and Parts consolidation, internal features, as built mechanisms; and, 4) Testing U Mechanical and Fatigue Testing; Physical properties; and, Particle size characterization. The RPC and its associated personnel and faculty are recognized as international leaders in Additive Manufacturing. They are heavily involved in growing and promoting the technology through technical organizations as officers, presenters, and featured speakers.

THE RESEARCH RESOURCES CENTER (RRC): The *in vivo* animal studies will be conducted in the RRC at the University of Louisville Health Sciences Campus. This facility contains approximately 19,450 sq. ft. of animal holding and related support space on a common level. The interior of the building is divided into separate zones called pods. Pods are used according to 1) the nature of activities they are to accommodate and 2) the requirements for functional and physical segregation of animals. Space dedicated to small animal housing includes a modified barrier with restricted access for transgenics and a biocontainment zone. Additional space is provided for large animal housing. Space provided for technical support includes modern surgical suites and laboratories for animal diagnostic and necropsy activities. The RRC has two aseptic surgical suites, which include an operator scrub area, an animal preparation area, an ICU, and an operating room. The U of L animal care and use program is supported by a well-trained technical staff (senior veterinary technician, laboratory animal technologist, laboratory animal technician, assistant laboratory animal technician, and animal caretaker) that are AALAS, LATg, LAT, ALAT, and AVMA, respectively, certified. In addition, the facility has three full-time veterinarians on staff. Finally, the RRC program is fully accredited by the American Association for the Accreditation of Laboratory Animal Care (AAALAC).

CENTER FOR REGULATORY AND ENVIRONMENTAL ANALYTICAL METABOLOMICS (CREAM) ANALYTICAL LABORATORY FOR METABOLOMICS FACILITY is a 1400 sq. ft laboratory in chemistry building room 316 is equipped for bioanalytical chemistry work. Dr. Zhang also has a 150 sq. ft office in the new Shumaker Research Building (SRB) room 349 outfitted with one 3.00 GHz Intel Core2 Duo workstation, one 1.6 GHz Intel Core2 Duo laptop computer, and one Samsung 3UinU1 laser printer. Full secretarial support is available to support Dr. Zhang's teaching and research activities. The support services include machine and electronic shops, library facilities, art and graphics shop, etc. Dr. Zhang has two other 150 sq. ft offices for

bioinformatics development in the SRB building (room 343 and 344) fully equipped with online computers and printer systems.

CORE PROTEOMICS LABORATORIES are directed by Jon B. Klein, MD, PhD and Michael L. Merchant, PhD. Dr. Klein is a Professor of Medicine and Biochemistry and holds the James Graham Brown Endowed Chair in Proteomics. Dr. Merchant is an Associate Professor in the Department of Medicine, University of Louisville and is the Technical Director of the Proteomics Laboratories. These facilities operate with the contributions of four technicians and one post-doctoral fellow. The Proteomics Laboratories have 1,475 sq. ft of dedicated space in the Donald Baxter Research Building for core projects. The MS instruments, all HPLC enabled, include a UHPLC-nanospray-Thermo Orbitrap Elite equipped with ETD fragmentation, a Thermo LTQ ion trap, TSQ triple quadrupole instrument, an ABI Q-Star qTOF instrument and ABI 4700 MALDI TOFUTOF. Additionally, one AB Biovision FPLC and one Dionex U3000 microflow instrument are utilized for preparative and semi-preparative protein and small molecular purification. Dr. Merchant and Dr. Klein each have 679 sq. ft of research space in the Donald Baxter Research Building. Dr. Merchant's space is used to conduct research funded by the NIDDKUNIH to confirm biomarkers of hypo-responsiveness to erythropoiesis stimulating agents as well as collaborative research projects. Dr. Klein's space is dedicated to research funded by the NIDDK – U01 Consortium for Biomarkers of Chronic Kidney Disease Research, NIDDK UM1 CureGN Consortium. All these laboratories are located in the state-of-the-art Donald E. Baxter Biomedical Research Building (opened in 1999).

BIOPHYSICS CORE LABORATORY consists of 1000 sq. ft. of laboratory space, which is located on the 2nd floor of the CTR Building. This laboratory was specifically designed to house the core facility, and features ten separate electrical circuits such that most instruments are provided with a dedicated power line. The laboratory has its own water purification system. Dr. Chaires' 120 sq ft office is located in the CTR building. The intellectual environment in the Brown Cancer Center is outstanding. The Cancer Biophysics Group is housed together on the 2nd floor of the CTR building to facilitate interactions. The group includes, in addition to Drs. Chaires and Trent; Dr. Hong Ye, and expert in X-ray crystallography. The Biophysics group holds regular meetings and group discussions to further their mutual interests. The Brown Cancer Center also has an active Molecular Targets group that holds weekly seminars. The Brown Cancer Center is an active, vibrant collection of clinical, translational, and basic scientist. Under the leadership of Dr. Donald Miller, the Center has recruited and hired over 80 new faculty members in the last 7 years.

MOLECULAR MODELING CORE M FACILITY. Dr. Trent is the Director of the Modeling Core at the JG Brown Cancer Center. The Modeling Facility moved to 800 sq ft. custom renovated space in the CTR Building in 2009. We created a Mac OSX grid cluster of over 25,000 processors which aids in virtual screening using Autodock, Surflex, and DOCK and provides over 800 CPU years a month. The computational lab

comprises of six G5/intel Macs, three PC's and a 440 2.6 MHz processor core IBM 1350 server with 24 TB attached storage on the second floor of the Clinical and Translational Research Building. A 2x2070 Tesla GPU computing machine is located in the Core as well as a 135TB storage unit.

MEDICINAL CHEMISTRY FACILITY. Dr. Burlison is the Director of the newly established Medicinal Chemistry Facility at the JG Brown Cancer Center. It is housed on the second floor of the CTRB, with 2000 sq ft of dedicated space. Medicinal chemistry is an integral part of an interdisciplinary approach towards the discovery, development and evaluation of new small molecules for the treatment of various indications. By delivering new chemical entities with drug-like properties through synthetic modification, medicinal chemistry may be utilized to develop structure-activity relationships, solve pharmacological problems, drug optimization, and to mitigate metabolic and toxicity liabilities. As a new initiative at the Brown Cancer Center lead by Dr. Trent, in August 2011 a new Medicinal Chemistry Facility that is capable of offering medicinal chemistry support and consultation for the Brown Cancer Center community has been set up. A Medicinal Chemist has been recruited to lead the new Facility which is housed in custom renovated 2000 sq. ft. space on the second floor of the CTR Building. Medicinal Chemistry Services we offer include: Optimization of lead compounds, provide synthetic and medicinal chemistry support, development of structure-activity relationships, improvement of ADMET properties in lead compounds, preparation of probes and fluorescently labeled derivatives, synthesis of known ligands for a molecular target, consultation on early stage drug discovery programs. . The facility is capable of rapidly synthesizing and characterizing small molecules to provide structure-activity relationships and lead optimization by improving physicochemical and drug-like properties. Equipment readily available to the Medicinal Chemistry Facility includes one or more of the following dedicated equipment: Agilent 400 MHz NMR equipped with an autosampler, Agilent HPLC/MS equipped with autosampler and a time-of-flight detector, Biotage Initiator Eight Microwave Synthesizer, Teledyne Isco Combiflash purification system, VWR sonicator water bath, VWR microcentrifuge galaxy, Mettler-Toledo balances, Buchi rotary evaporators, seven chemical fume hoods, and standard organic chemistry glassware and equipment.

NUCLEAR MAGNETIC RESONANCE (NMR) CORE FACILITY is a purpose-built suite in the imaging wing of the James Graham Brown Cancer Center (JGBCC) that occupies 2,365 sq. feet. This comprises a console room (966 sq. ft.), a separate magnet room with its own climate control and ultra-low vibration concrete floor (1,020 sq. ft.), a utility room where compressors and water chillers are housed (202 sq. ft.), and the manager's office (177 sq. ft.). The facility can be entered only via a keyed security door, which is accessed by authorized personnel only. The console room also houses bench space for sample manipulation, including a chemical hood, deionized water supply, balance, microfuge, pH meter, chemical storage cupboard, and both 4° and U 25°C refrigerators for sample storage. Workstations are lined along one bench,

where a small library of reference NMR-based books and journals are kept. The manager's office leads off the main console room, and is equipped with personal computers, a workbench and has Internet access. The facility has a chemical hood, de-ionized water, balance, pH meter and microfuge, plus U25°C/4°C storage. General information is available on the Cancer Center Web site (http://www.browncancercenter.org/research/shared-research-facilities/nmr-suite/) that describes general capabilities as well as fee structures.

ORAL IMMUNOLOGY AND INFECTIOUS DISEASES CORE FACILITY is housed in the School of Dentistry Room 214 (~1100 sq. ft) and includes pH meters (2), CO2 incubators (4), cell culture hoods (2), nanodrop spectrophotometer, BioRad and Thermo uV/vis spectrophotometers (3), Applied BioScience 7500 real time PCR, BioRad MyCycler PCR (3), microbiologic incubators (3), two station anaerobic culture chamber, baking ovens (2), LabConco lyophilizer, Sorvall high speed centrifuges (2), Sorvall WX ultracentrifuge, Sorvall Legend tabletop centrifuge, liquid nitrogen tanks (3), water baths (3), Mettler analytical balance, Ohaus Scout Scale, Agilent 2100 BioAnalyzer, Eppendorf microcentrifuges (2), Zeiss microscopes (2), Olympus FluoView 500 laser scanning confocal microscope linked to Volocity Image analysis software, BD FACSCalibur cell sorter, Alpha Innotec FluorChem imaging system, Amersham FPLC system, a Blitz surface plasmon resonance instrument, and sonicators (2).

MOLECULAR, CELL AND CRANIOFACIAL BIOLOGY AND THE BIRTH DEFECTS CENTER CORE FACILITY consists of Microscopy/Imaging: Arcturus Pixcell IIe Laser Capture Microdissection System with epifluorescence optics; Nikon Eclipse TE2000U inverted phase contrast microscope with epifluorescence optics and color digital & high resolution monochrome cameras and link to Metamorph Image Analysis System; four Nikon stereoscopic zoom SMZ 1500 microscopes with epifluorescence optics, color digital & high resolution monochrome cameras and links to Metamorph Image Analysis System; Nikon Optiphot microscope with epifluorescence optics, color digital & high resolution monochrome cameras and link to Metamorph Image Analysis System; Nikon SMZ800 Stereoscope with micromanipulators/ injectors; Narashige PN3U Needle Puller; LKB Nova Ultra microtome; two Leica CM 1900 Cryostats; two Leica 2150 RM Microtomes; Shandon Histocenter Embedding Station. Additional analytic equipment include: Qiagen Pyromark Q24 Pyrosequencer; Applied BioSystems ViiA 7 realUtime PCR system with 'FAST' kinetic 384Uwell, and Array Card block; two Perkin Elmer 9700 Thermal Cyclers; two Applied Biosystem PRISM Sequence Detection Systems (TaqMan RealUTime Quantitative PCR); Agilent 2100 "Lab on a Chip" Bioanalyzer; NexCellom CellCounter; Affymetrix GeneChip System (Fluidics Station, Hybridization Station, Scanner) for mRNA, miRNA, CHIP arrays, and SNP chip; Pharmacia Gene Quant Pro spectrophotometer; Victor X3 Multilabel Plate Reader; NanoDrop NDU1000 UVUVis Spectrophotometer; Turner Luminometer; GE ImageQuant 4000 Image Analysis System; UVP BioDocUIT Imaging

System; Molecular Dynamics StormPhosphoimager; Delta300 Liquid Scintillation System.

8. Clearly state the admission, retention, and completion standards designed to encourage high quality.

The Speed School of Engineering has rigorous standards for admission into graduate programs, and those standards will apply to the MS BE program as well. Applicants must meet Speed School graduate admission requirements along with additional program requirements. Applicants must, as a minimum, have completed a Bachelor's Degree in Engineering from an ABET accredited program or a Bachelor's Degree in Medical Physics from an accredited program. Successful applicants will typically have a 3.00 cumulative GPA in their BS in Engineering. Applicants with an undergraduate GPA of 2.75 will be considered for provisional acceptance; however, they must maintain a 3.00 GPA at a minimum in their first year of study or they will not be allowed to continue in the program. Applicants must submit: 1) transcripts of all college-level courses; 2) two letters of recommendation; 3) a written statement by the applicant describing previous experience related to bioengineering; 4) a statement as to how the MS BE will allow them to fulfill their career goals; and, 5) GRE verbal, quantitative and writing assessment-analytical scores. Ideal applicants will have GRE scores at or above the 60th percentile on verbal and quantitative sections. Students whose native language is non-English or degree is from a non-US accredited institution are required to submit TOEFL scores (administered by the Educational Testing Service). A minimum TOEFL score of 79 or higher on the internet-based test or 550 or higher on the paper-based test is required. Alternatively a minimum of 6.5 on the International English Language Testing System will be accepted.

Student performance will be monitored and assessed throughout their program using the following metrics to assure students completing the program have an advanced level of competency in the field of Bioengineering.

- Course performance (GPA)
- Peer-reviewed conference papers by students as first or co-authors
- Peer-reviewed journal papers by students as first authors or co-authors
- Presentations at regional, national and international conferences by students
- Intellectual property declarations submitted, filed and/or issued with students as co-inventors
- Thesis defense performance
- Bioengineering Design/Research Project performance

a. Indicate expected faculty to student ratio:
There are 14 participating faculty who are listed on the SACS Faculty Roster Form. By the 5th year we anticipate 30 students will be in the program, yielding faculty to student ratio of approximately 1:2.

9. Clearly state the degree completion requirements for the program.

Students must meet degree requirements established by the Speed School of Engineering, in addition to Program requirements. The program must be completed with a 3.00 GPA or higher in all graduate courses used to satisfy degree requirements. MS BE students must complete 30 credits, including either MS Thesis (BE 698 – 6 credits) or Bioengineering Non-Thesis Design/Research Project (BE 691 – 3 credits), and two terms of Bioengineering Seminar (BE 601 – 1 credit each). Students must successfully defend their MS Thesis or Bioengineering Design/Research Project. It is recommended that students submit their MS Thesis as a peer-reviewed journal manuscript under the supervision of their mentor. All degree requirements must be completed within six years from admission into the program.

10. Provide the following information for the program and for each concentration (some categories may not apply to all programs):

	Thesis Option	Non-Thesis Option
a. Total number of hours required for degree	30	30
b. Number of hours in degree program core	15	15
c. Number of hours in concentration	9	12
d. Number of hours in guided electives	6	3
e. Number of hours in free electives	0	0

a. ~~Total number of hours required for degree: 30 credits~~
b. ~~Number of hours in degree program core: 15 credits~~
c. ~~Number of hours in concentration: 9 credits for thesis; 12 credits for non-thesis~~
d. ~~Number of hours in guided electives:~~
e. ~~Number of hours in free electives:~~

11. Describe how the proposed program will articulate with related programs in the state. It should describe the extent to which student transfer has been explored and coordinated with other institutions. Attach all draft articulation agreements related to this proposed program.

Transfer of credits from a Master's Degree in engineering from an accredited institution is permitted. However, the number of transfer credits (up to a maximum of 6 credit hours) will be evaluated on a case-by-case basis by the Program Director, which will forward the petition to the Dean of the Speed School of Engineering for final approval. Sufficient course descriptions and a transcript must accompany the petition so that the request can be evaluated.

12. List courses under the appropriate curricular headings.

Working with their advisor, students must complete a Plan of Study identifying each course to be taken by the student and its associated term. The Plan of Study must be reviewed and approved each term by the student's advisor. The Plan of Study may be modified with approval from the student's advisor. A list of course descriptions is shown in Appendix C.

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Core Courses			
Prefix & Number	Course Title	Credit Hours	New
BE 621	Bioinstrumentation	4	N
BE 654	Advanced Physiology for Engineers	3	N
BE 601	Bioengineering Seminar	1 ea. (2)	N
CHE 686 ~~or ME 565~~	~~Chemical Engineering Analysis or~~ Advanced Engineering Math	3	N
BE 695	Research Design & Methods	3	N
	TOTAL CORE CREDIT HOURS	15	
Thesis Option			
Prefix & Number	Course Title	Credit Hours	New
BE 698	Bioengineering MS Thesis	6	Y
Non-Thesis Option			
Prefix & Number	Course Title	Credit Hours	New
BE 691	Bioengineering Non-Thesis Design/Research Project	3	N
Technical Elective Courses in Concentration Areas[1] (9 credits for thesis option; 12 credits for non-thesis option)			
Molecular and Tissue Engineering			
Prefix & Number	Course Title	Credit Hours	New
BE 552	Tissue Engineering	3	N
BE 553	Nanoscale Bioengineering	3	N
BE 605	Tissue & Molecular Biology Techniques	3	N
BE 650	Advanced Biomaterials	3	N
BIOC 680	Biomolecular Interactions	3	N
BIOC 668	Molecular Biology	3	N
BIOC 611	Biochemical & Molecular Methods	3	N
Bioimaging and Biocomputational Modeling			
Prefix & Number	Course Title	Credit Hours	New
BE 540	Machine Learning in Medicine	3	N
BE 542	Medical Image Computing	3	N
BE 600	Modeling of Biological Phenomena	3	N
BE 640	Computational Methods for Medical Image Analysis	3	N
CECS 622	Simulation and Modeling of Discrete Systems	3	N
CECS 624	Advanced Simulation	3	N
CECS 627	Digital Image Processing	3	N
CECS 641/ECE 641	Medical Image Systems	3	N
CECS 643/ECE 643	Introduction to Biomedical Computing	3	N
CECS 660	Introduction to Bioinformatics	3	N
Bioelectrical and Biomedical Devices			

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Prefix & Number	Course Title	Credit Hours	New
BE 524	Labview for Engineering	3	N
BE 680	BioMEMS	3	N
BE 581	Advanced CAD and Manufacturing	3	N
ECE 543	Microfabrication and MEMS[2]	3	N
BE 683	Artificial Organs	3	N
BE 611	Cardiovascular Dynamics	3	N
BE 650	Advanced Biomaterials	3	N
Biomechanics and Rehabilitation			
Prefix & Number	Course Title	Credit Hours	New
BE 658	Injury Biomechanics	3	N
BE 639	Rehabilitation Engineering	3	N
BE 611	Cardiovascular Dynamics I	3	N
BE 581	Advanced CAD and Manufacturing	3	N
BE 630	Biomechanical Computer Modeling of Human Movement	3	N

Notes:

1 – Technical electives must include 9 credits of BE-prefix courses. Deviations from this requirement require a waiver approved by the student's advisor and Department Chair.
Students may take technical electives from more than 1 concentration area.
Fulfillment of technical elective requirements with courses outside of the concentration area electives require permission from the student's advisor and Department Chair.

~~2 – Course requires additional $500 fee.~~

13. Describe planned alternative methods of program delivery involving greater use of technology, distance education, and/or accelerated degree designs, to increase efficiency, better address student educational and workforce needs, and maximize student success, for both traditional and non-traditional students.

~~Courses~~ Most courses will be delivered in a face-to-face classroom setting style lecture or laboratory setting. However, some technical elective courses ~~may be~~are available online via distance learning, with increased online course offerings anticipated ~~in~~ the future.

C. Program Demand/Unnecessary Duplication

Proposed programs must respond to the needs of the academy and to larger economic and social environments. Thus, the institution must demonstrate demand for the proposed program. All proposed programs must address student demand. Programs must also address either employer demand or academic disciplinary needs.

1. **Student Demand: Clearly describe all evidence of student demand, typically in the form of surveys of potential students and/or enrollments in related programs at the institution.**
    a. Provide evidence of student demand at the regional, state, and national levels.

A 2015 report[5] by Dr. Brian Yoder from the *American Society of Engineering Education*, states that awarded bioengineering undergraduate degrees have increased nearly 95%, Master's degrees have increased by 66% and Doctoral degrees have increased by 130% between 2006 and 2015. These significant increases in number of undergraduate and graduate bioengineering degrees awarded clearly demonstrate the student demand for such programs.

b. Identify the applicant pool and how they will be reached.
Prospective students will be those who have completed a Bachelor's degree in engineering from an ABET accredited school or those who have completed a Bachelor's degree in Medical Physics.

c. Describe the student recruitment and selection process.
Students will be recruited through web-based marketing of the program, along with advertisement of the program at regional, national and international bioengineering society conferences. Program announcements will be sent to top-ranked engineering schools and bioengineering focused companies.

d. Identify the primary feeders for the program.
Accredited engineering schools across the US, including U of L, will serve as feeders for the program. Additionally, we currently have International Memoranda of Understanding with Chiang Mai University, Mansoura University and Abu Dhabi University indicating their interest in our Bioengineering educational programs and a collaborative exchange of students and faculty. Given the national and international reputation of our BE faculty, it is reasonable to expect that engineering graduates from across the nation and worldwide will find our program attractive.

e. Provide any evidence of a projected net increase in total student enrollments to the campus as a result of the proposed program.
According to an *American Society of Engineering Education* report[6] previously cited, 2390 students enrolled for a Master's degree in bioengineering/biomedical engineering in 2006 in the US. This number increased to 3770 students in 2015; nearly a 60% increase over 9 years, demonstrating significant student demand.

As additional evidence, in 2009 our first MEng in Bioengineering graduating class consisted of four students, while in the 2014 academic year, 25 students completed our MEng degree program. Thus, it is reasonable to anticipate a net increase in student enrollment associated with the MS BE program.

f. Project estimated student demand for the first five years of the program.

5 https://www.asee.org/papers-and-publications/publications/college-profiles/15EngineeringbytheNumbersPart1.pdf
6 https://www.asee.org/papers-and-publications/publications/college-profiles/15EngineeringbytheNumbersPart1.pdf

Based on similar programs across the country and faculty resources during the first five years of the program, we project 10-12 applicants per year with a projected enrollment of 6-8 new students admitted and enrolled annually. The first graduates of the program are expected by the 2nd year of the program.

Table 1. Estimate of number of students in MS BE program on an annual basis.

Academic Year	Degrees Conferred	Majors (Headcount) – Spring Semester
2018-19	0	8
2019-20	4	16
2020-2021	12	2~~0~~4
2021-2022	20	~~30~~20
2022-2023	28	~~30~~20

2. **Employer Demand: Clearly describe evidence of employer demand. Such evidence may include employer surveys, current labor market analyses, and future human resources projections. Where appropriate, evidence should demonstrate employers' preferences for graduates of the proposed program over persons having alternative existing credentials and employers' willingness to pay higher salaries to graduates of the proposed program.**
    a. Describe the types of jobs available for graduates, average wages for these jobs, and the number of anticipated openings for each type of jobs at the regional, state, and national levels.

In 2012, the President's Council of Advisors on Science and Technology – an advisory group of the nation's leading scientists and engineers – set forth a goal, based on economic forecasts, to produce one million additional graduates with degrees in science, technology, engineering and mathematics. Employment opportunities for bioengineers are predicted to continue growing faster than the average for all occupations through 2020 as reported by CNNMoney[7] with a 10-year job growth of ~62%. The Bureau of Labor Statistics predicts a 23.1% increase in employed bioengineers from 2014 to 2024.[8] Bioengineers enjoy both a growing job market and attractive compensation (median annual salary: $85,620 in May 2016[9]). The mean annual salary for bioengineers in Kentucky was $70,430 in 2016, with a 90th percentile salary of $114,420.[10] Bioengineers have the gratification that comes from working to meet the needs of society and improving quality of life, having opportunities to work in industry, universities, hospitals, research institutes, medical institutions and government agencies. 20,950 bioengineers are currently employed in the US, many working in the fields of medical equipment and supply manufacturing, scientific research and development, instrumentation manufacturing, and pharmaceutical manufacturing.

7 http://money.cnn.com/gallery/pf/jobs/2013/11/13/fastest-growing-jobs/
8 Bureau of Labor Statistics – Employment Projections, May 2016
9 Bureau of Labor Statistics – Employment Projections, May 2016
10 Bureau of Labor Statistics – Occupational Employment Statistics, May 2016

With the advancements in medicine, more individuals are seeking biomedical solutions to their health problems. Although bioengineering encompasses many areas, one of its primary functions is to develop better solutions for the prevention, diagnosis, and treatment of disease, patient rehabilitation, and to improve overall health and quality of life.

3. **Academic Disciplinary Needs: Clearly describe all evidence justifying a new program based on changes in the academic discipline or other academic reasons.**

Development of the MS BE Program is based upon demand in this relatively new discipline. There are no known or anticipated changes in this academic discipline at this time.

4. **Similar programs: A new program may serve the same potential student population, the proposed program must be sufficiently different from existing programs in the state or access to existing programs must be sufficiently limited to warrant initiation of a new program.**
   a. Identify similar programs in other Southern Regional Education Board (SREB) states and in the nation.
      In addition to our existing MEng in BE degree which is offered only to U of L students who have completed their BS BE, there is a MS in Biomedical Engineering (BME) offered through the University of Kentucky (UK). Within the SREB states there are approximately 25 existing MS in Bioengineering or MS in Biomedical Engineering programs available. Currently there are approximately 271 MS in Bioengineering or MS in Biomedical Engineering programs in the US.

   b. If similar programs exist in Kentucky,
      i. Does the proposed program differ from existing programs? If yes, please explain.

Although the University of Kentucky has a MS in BME program, the proposed U of L MS BE differs in its focus on translational bioengineering. This focus builds upon our strong U of L BE faculty collaborations with U of L Medical School and Dental School faculty, enabling translation of therapeutic devices and techniques into clinical practice. This approach has been supported through multiple foundation and federal grants to BE faculty. These existing collaborations will benefit U of L MS BE students through participation in translational bioengineering projects which will serve as the basis for BE thesis and non-thesis projects. In contrast, the UK MS BME program does not have a translational focus within their curriculum. ~~The proposed U of L MS BE degree is similar to the University of Kentucky MS in BME. However~~Additionally, the U of L MS BE program enables students to do a Biomedical Research Project in lieu of a thesis, which may be desirable for students who are currently working or who do not plan ~~to go on~~ to work in research and development or academia. ~~Moreover, Bioengineering faculty at U of L have strong collaborations with U of L Medical School and Dental School faculty, translating therapeutic devices and techniques into clinical practice supported through multiple foundation and federal grants to BE faculty. These existing collaborations will benefit U of L MS BE students through participation in translational~~

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~~projects which will serve as the basis for BE thesis and non-thesis projects.~~ Despite these differences, BE faculty at U of L and UK have begun to collaborate, enabling students from the UK MS BME program to enroll in U of L BE online courses. We anticipate expansion of this collaboration on educational programs in bioengineering between the two universities.

ii. Does the proposed program serve a different student population (i.e., students in a different geographic area) from existing programs? If yes, please explain.

Yes, this degree program will serve students from the metropolitan Louisville area, the ~~eastern~~ western portions of Kentucky and the southern most Indiana counties. Additionally, our program will be unique given that a number of international memoranda of understanding have been obtained from universities in Egypt, China and Abu Dhabi.

iii. Is access to existing programs limited? If yes, please explain.

There is no evidence that access to existing programs is limited.

iv. Is there excess demand for existing similar programs? If yes, please explain.

We believe the demand in existing programs is robust, and we expect increasing demand given the need for bioengineers in the workforce. Moreover, the statewide STEM initiative to improve Kentucky's position for success in the knowledge-based economy by expanding and strengthening educational and economic development opportunities in science, technology, engineering, and mathematics should increase the demand for programs such as the MS BE. The Kentucky General Assembly has the goal of substantially increasing number of mathematicians, scientists, and engineers in the Kentucky workforce to foster economic growth and provide high quality jobs for Kentuckians.

v. Will there be collaboration between the proposed program and existing programs?
    i. If yes, please explain the collaborative arrangements with existing programs.
    ii. If no, please explain why there is no proposed collaboration with existing programs.

    There are no ~~plans for~~formal ~~collaboration~~ collaborative agreements with the existing program at this time. However, students from the UK BME program have enrolled in U of L BE online courses. By moving towards offering some BE courses online, we anticipate furthering the ability of UK students to enroll in our courses. ~~However~~Moreover, collaborative faculty research initiatives between UK and U of L could potentially provide students with learning experience opportunities that bridge both universities.

D. Cost and Funding of the Proposed Program

The resource requirements and planned sources of funding of the proposed program must be detailed in order to assess the adequacy of the resources to support a quality program. This assessment is to ensure that the program will be efficient in its resource utilization and to assess the impact of this proposed program on the institution's overall need for funds.

1. **Will this program require additional resources?**
    a. If yes, provide a brief summary of additional resources that will be needed to implement this program over the next five years.

    Primary coursework for the MS in Bioengineering will be from the Department of Bioengineering's current course offerings. Electives may be taken from other departments within Speed School of Engineering or from the Department of Biochemistry. However, increases in course enrollment anticipated in Years 2-5 will require additional sections of core courses be offered, leading to an increase in faculty workload. Thus, 1 Graduate Teaching Assistant (GTA) is requested in Year 2, and 2 GTAs are requested in Years 3, 4 and 5, continuing thereafter.

    Additionally, increased student enrollment will strain existing classroom and laboratory facilities. However, we anticipate offering more online BE courses will serve to offset classroom/laboratory demands.

2. **Will this program impact existing programs and/or organizational units within your institution?**
    a. If yes, please describe the impact.

    This program will not impact existing programs or organizational units at U of L.

3. **Provide adequate documentation to demonstrate sufficient return on investment to the state to offset new costs and justify approval for the proposed program.**

In addition to advancing Kentucky's STEM initiatives by producing highly trained bioengineers, this program is expected to grow overall enrollment at U of L. We project an enrollment of approximately 30 students by Year 4 or 5, yielding annual tuition revenue of roughly $928,603. This revenue will offset the investment cost of 2 new GTA's ($119,360) needed to deliver the program. Less tangible benefits will also potentially include attracting graduates of the MS BE program into our ISSTBE PhD program. Those who join the workforce following graduation from the MS BE program and choose to remain in Kentucky will contribute to growth of Kentucky's economy and will contribute to improvements in the quality of life of Kentuckians.

Cost/Funding Explanation

Complete the following table for the first five years of the proposed program and provide an explanation of how the institution will sustain funding needs. *The total funding and expenses in the table should be the same, or explain sources(s) of additional funding for the proposed program.

A. Funding Sources, by year of program	**1st Year**	**2nd Year**	**3rd Year**	**4th Year**	**5th Year**
Total Resources Available from Federal Sources New Existing					
Narrative Explanation/Justification					
Total Resources Available from Other Non-State Sources New Existing					
Narrative Explanation/Justification:					
State Resources New Existing					
Narrative Explanation/Justification:					
Internal Allocation Internal Reallocation					
Narrative Explanation/Justification: The source and process of allocation and reallocation should be detailed, including an analysis of the impact of the reduction on existing programs and/or organization units.					
Student Tuition **New**	**$226,392**	**$466,368**	$599,939 ~~$719,927~~	$616,918 ~~$903,730~~	$633,898 ~~$928,603~~
Narrative Explanation/Justification: Projected tuition revenues are based upon full-time enrollment for matriculation in an average of 5 terms. A resident/non-resident Master's student ratio of 52%/48% was used for tuition calculations based on the prior 3 years of Speed School graduate enrollment demographics. Full-time tuition for a resident was $6123 and for non-resident $12,743. A 3% annual tuition increase was incorporated into projections. However, we believe this program has the potential to attract new non-resident students to the university from neighboring states and abroad which will increase tuition revenues beyond projected values. We currently have International Memoranda of Understanding with Chiang Mai University, Mansoura University and Abu Dhabi University indicating their interest in our Bioengineering educational programs and a collaborative exchange of students and faculty.					
TOTAL	**$226,392**	**$466,368**	$599,939 ~~$719,927~~	$616,918 ~~$903,730~~	$633,898 ~~$928,603~~

B. Breakdown of Budget Expenses/Requirements	**1st Year**	**2nd Year**	**3rd Year**	**4th Year**	**5th Year**
Staff					
Executive, Administrative, Managerial New Existing					
Other Professional New Existing					
Faculty New Existing					
Graduate Assistants **New**		**$44,388**	**$112,508**	**$115,884**	**$119,360**
Student Employees New Existing					
Narrative Explanation/Justification: One (1) new Graduate Teaching Assistants (GTA) is requested in Year 2, and 2 new GTAs are requested in Years 3, 4 and 5, continuing thereafter. Funds for GTA lines include a stipend, health insurance, and 12 months full-time graduate tuition charged at the resident rate for Year 2, and for both the resident rate and non-resident rate in Years 3, 4 and 5 (2 GTAs in each year). A 3% annual inflation rate was applied to the stipend, tuition and health insurance cost.					
Equipment and Instructional Materials New Existing					
Narrative Explanation/Justification:					
Library New Existing					
Narrative Explanation/Justification:					
Contractual Services New Existing					
Narrative Explanation/Justification					

Academic and/or Student Services New Existing					
Narrative Explanation/Justification					
Other Support Services New Existing					
Narrative Explanation/Justification					
Faculty Development New Existing					
Narrative Explanation/Justification					
Assessment New Existing					
Narrative Explanation/Justification					
Other New Existing					
Narrative Explanation/Justification:					
TOTAL **New**		**$44,388**	**$112,508**	**$115,884**	**$119,360**

E. Program Review and Assessment

Describe program evaluation procedures for the proposed program. These procedures may include evaluation of courses and faculty by students, administrators, and departmental personnel as appropriate. Program review procedures shall include standards and guidelines for the assessment of student outcomes implied by the program objectives and consistent with the institutional mission.

1. For each assessment method, please provide direct indicators of achievement of program-level student learning outcomes and frequency of data collection:
    a. Which components will be evaluated?

Table 2. Student learning outcomes to be assessed and associated indicators of achievement.

Student Learning Outcome	**Indicators of Achievement**
a) demonstrated advanced level of bioengineering knowledge	Achievement of one or more of the following: 1) submitted first-authored refereed journal and/or conference paper

	2) intellectual property based upon student-developed technology filed, issued and/or licensed to industry 3) student research-related award 4) successful defense of thesis or bioengineering research project
b) an understanding of the clinical relevance bioengineering topics	Achievement of: 1) successful defense of thesis or bioengineering research project
c) an understanding of contemporary bioengineering topics	Bioengineering Seminar Series attendance for 2 terms
d) ability to effectively communicate advanced knowledge of bioengineering orally and in writing	Achievement of one or more of the following: 1) presentation at regional, state, national or international conference 2) accepted first-authored refereed journal and/or conference paper 3) successful defense of thesis or bioengineering research project

b. When will the components be evaluated?
Components will be evaluated annually.

c. When will the data be collected?
Data will be collected each term.

d. How will the data be collected?
Data will be collected through plans of study prepared by the student and their advisor.

e. What will be the benchmarks and/or targets to be achieved?
See Table 2 above.

f. What individuals or groups will be responsible for data collection?
The Department Chair, MS BE Program Director, Department Associate Chair, and Department Administrators will be responsible for data collection, but each advisor will be responsible for submitting the data for their students.

g. How will the data and findings be shared with faculty?
Faculty will be responsible for reporting data for each of their advisees. Results of data analysis will be shared with faculty at an annual BE faculty and staff retreat to review BE programs, as well as at faculty meetings as deemed appropriate.

i. How will the data be used for making programmatic improvements?

As a part of the annual BE retreat findings will be evaluated and as needed recommendations for improvement will be discussed.

2. **What are the measures of teaching effectiveness?**
   Course evaluations provide direct student feedback to course instructors who are then able to address areas needing improvement. In addition, course evaluations are measured outcomes of teaching performance; as a result, the Department Chair will discuss and address any identified weaknesses with instructors during their annual review.

3. **What efforts to improve teaching effectiveness will be pursued based on these measures?**

   Course instructors have access to the Delphi Learning Center's monthly workshops designed to improve teaching effectiveness. Typically, these one-hour training workshops are designed to present new teaching approaches, education paradigms, and instruction of emerging technology to improve teaching effectiveness.

4. **What are the plans to evaluate students' post-graduate success?**

   Short-term post-graduate success will be defined based upon placement in industry, government agency and academic positions. Intermediate and long-term success will be characterized by contributions to the field of bioengineering as evidenced by employment advancement, scientific publications, patents issued, honors, start-up companies established, and professional attainment by alumni (targets for these outcome measures are shown below in Table 3). The MS BE program will survey alumni in parallel with the SIGS Alumni Tracking program in the first year following graduation and every 5 years thereafter.

Table 3. Program assessment: targets for post-graduate measures of success

F. Outcome measure	G. Target within 5 years post-graduation
Employment advancement	30% of alumni
Scientific publications (co-author on peer-reviewed journal paper or conference proceeding)	50% of alumni
Patents submitted or issued	20% of alumni
Honors	20% of alumni
Start-up companies established	10% of alumni

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Appendix A

Bioengineering Faculty

Faculty	Department
Bertocci, Gina	Bioengineering
Bertocci, Karen	Bioengineering
El Baz, Ayman	Bioengineering
Frieboes, Hermann	Bioengineering
Giridharan, Guruprasad	Bioengineering
Keynton, Robert	Bioengineering
Koenig, Steven	Bioengineering/Cardiovasc & Thoracic Surgery
Kopechek, Jonathan	Bioengineering
O'Toole, Martin	Bioengineering
Roussel, Tommy	Bioengineering
Soucy, Kevin	Bioengineering/Cardiovasc & Thoracic Surgery
Soucy, Patricia	Bioengineering
Steinbach, Jill	Bioengineering
Voor, Michael	Bioengineering/Orthopedic Surgery

Appendix B

Letters of Support

UNIVERSITY OF LOUISVILLE.
J.B. SPEED SCHOOL OF ENGINEERING

Office of the Dean

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September 6, 2018

Dr. Beth Boehm
Provost
University of Louisville
Louisville, KY 40292

Dear Provost Boehm,

I would like to express my complete support for the proposal of a Master of Science program within the Department of Bioengineering. It is my belief that the proposed program will be a great addition to the current offerings of the Speed School of Engineering. The addition of this Master of Science program will open the door to students with Bachelor's degrees in Bioengineering from other institutions. According to market research, there is a demand for programs such as this. We believe that the enrollment for this degree will quickly meet the goals of the Department, and of the Unit.

The proposal submitted for this program has been well thought out and thoroughly planned. It was unanimously approved by the BE faculty on June 27, 2018 and unanimously recommended for approval by the J.B. Speed School of Engineering Graduate Education Committee on August 8, 2018. Implementation of this program will be possible without any major disruption to other degree programs. The growth brought about by this new offering will also further the goals of the University in various areas including enrollment growth and research.

Students in this new MSBE program will benefit from the BE department's world-class laboratory facilities, research endeavors, and faculty. Additionally, the J.B. Speed School of Engineering will provide the BE department with two (2) additional GTA positions to support this new MSBE program. Speed School will include the stipend of $1834/month for 12 months and health insurance for these 2 additional GTA positions to our FY20 CAR budget while SIGS will provide resident tuition awards for both positions.

University of Louisville • Louisville, KY 40292
P: 502.852.6281 F: 502.852.7033 E: speed@louisville.edu W: louisville.edu/speed

I would like to offer my strongest support for this proposal to add a Master of Science in Bioengineering degree program here at the JB Speed School of Engineering. Please let me know if you have further questions. Thank you for your consideration.

Sincerely,

Emmanuel G. Collins
Dean

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UNIVERSITY OF LOUISVILLE

SCHOOL OF INTERDISCIPLINARY & GRADUATE STUDIES

Paul DeMarco, Ph.D.
Acting Vice Provost for Graduate Affairs
Acting Dean of the School of
Interdisciplinary and Graduate Studies
University of Louisville
Louisville, KY 40292
502.852.5110
paul.demarco@louisville.edu

September 6, 2018

Dear Dean Collins,

I've reviewed the proposal for a Master of Science in Bioengineering submitted by the Department of Bioengineering. This is a well prepared proposal that comes at a time of strong need for individuals with graduate degrees in bioengineering. Graduate programs that are capable of robust enrollment, as I predict for this program, also serve our larger university goal of increasing overall enrollment and growing our student body.

I'm pleased to see the commitment from the Speed School for two permanent (CAR) Graduate Teaching Assistant lines in support of the program. Those scholarships will help recruit strong students to the program and help with retention and persistence toward degree of the students who receive these awards, as well as provide them with professional development opportunities while in the graduate program.

Because of your permanent commitment of funds to support stipends and health insurance for these scholarships, the School of Interdisciplinary and Graduate Studies will provide matching resident tuition awards for these two scholarship lines from our tuition remission budget. Students who receive these tuition awards must be in full-time status and making satisfactory progress towards degree to remain eligible for the awards.

We fully support this proposal and look forward to the first cohort of students to be admitted to the program.

Sincerely,

Paul DeMarco, Ph.D.

Ayman El-Baz
Professor and Chair of Bioengineering
Coulter Fellow, University Scholar

January 29, 2018

RE: MS Degree in Bioengineering Proposal
Letter of Support

Dear Dr. Bertocci:

It is with great enthusiasm that I am writing in full support of the Master of Science (MS) program in Bioengineering. The departmental faculty and I have reviewed the proposal and we look forward to MS students enrolling in our engineering courses. In addition, our faculty are committed to working with MS students to serve as mentors and dissertation advisors. This program will create excellent opportunities for collaborations within the current academic and research programs in the schools of engineering, medicine, dentistry, business and more. Currently, our MEngs students can only enroll from within the Speed School at UofL. The MS program will enable students from other universities, both nationally and internationally, to enroll in our Master's program. The MS program is crucial to implement a joint graduate program with international universities. We have obtained Letters of Intent from five international universities. The overall outcomes of the program will certainly yield tremendous benefits to the students and faculty, and to the university as a whole. I look forward to working with you to assist in any way I can to make sure the program is successful. Best of luck as this moves forward!

Please do not hesitate to contact me for any information.

Sincerely,

Ayman El-Baz, PhD.
Professor and Chair of Bioengineering
Coulter Fellow, University Scholar
Speed School of Engineering
University of Louisville
Louisville, KY 40292
Office: (502) 852-5092
Fax: (502) 852-1577
Email: aselba01@louisville.edu

UNIVERSITY OF LOUISVILLE
UNIVERSITY LIBRARIES

Office of the Dean

October 23, 2017

Connie Shumake
Office of the Provost
University of Louisville
Louisville, KY 40292

Connie,

We have been asked to provide a letter of support for the proposed Master of Science in Bioengineering. The University Libraries have prepared an analysis of their ability to support the new degree. The review indicates that, when compared to peer institutions, our journal and database collections are adequate in this area though several databases are noted that should be added if resources are available in the future. The review also notes that the ability to support this program is dependent on quickly fili ng the STEM librarian position that is currently vacant as there is no other librarian in the Libraries with the credentials required by accreditors to support the program.

I am attaching a copy of our review report for your records. Please contact us if you have any questions or need additional information.

Sincerely,

Robert E. Fox, Jr.
Dean, University Libraries

Cc: Gina Bertocci
Sue Finley
Tyler Goldberg

University of Louisville . Ekstrom Library, Room 203 . Louisville, KY 40292
P: 502.852.6745 **F**: 502.852.7394 **W**: Louisville.edu/library

EVALUATION OF LIBRARY RESOURCES

ESSENTIAL TO THE SUPPORT OF:

MASTER OF SCIENCE BIOENGINEERING

Susan Finley
Business Librarian

And

Tyler Goldberg
Head, Technical Services & Collection Development

Dean Robert E. Fox, Jr.
University Libraries
October, 2017

OVERVIEW

The University of Louisville (UofL) Libraries are comprised of five separate libraries: Ekstrom Library serving humanities, social sciences, life sciences, business, engineering, physical sciences, and technology; Kornhauser Health Sciences Library; Anderson Music Library; Bridwell Art Library; and the Law Library. University Archives and Special Collections center is also part of the UofL library system. Materials relevant to bioengineering are found primarily in Ekstrom Library, and secondarily in Korhauser Health Science Library.

UofL's library system supports instructional and research needs of over 22,000 full and part-time students and more than 7,000 faculty and staff. UofL belongs to the Association of Research Libraries (ARL), an organization of North American libraries affiliated with 123 large, comprehensive research institutions, as well as the State-Assisted Academic Library Council of Kentucky (SAALCK), and Kentuckiana Metroversity, a consortium of Louisville area libraries.

UofL's Department of Bioengineering currently offers an ABET accredited Master of Engineering degree that is limited to students with a Bachelor of Science in Bioengineering from UofL. The proposed Master of Science (MS) in Bioengineering degree program will be open to non-UofL graduates with undergraduate degrees in engineering. This report compares UofL's library resources to six benchmark institutions which offer MS degrees in Bioengineering: Temple University (TU), University of Alabama at Birmingham (UAB), University of California - San Diego (UCSD), University of Illinois at Chicago (UIC), University of Pittsburgh (PITT), and University of Utah (Utah). All six benchmark institutions also offer PhD degrees in Bioengineering.

COLLECTIONS

I. Book Collection

According to WorldCat, UofL has 10,319 books on the subject of bioengineering. The majority are housed at Ekstrom Library and the remainder in Kornhauser Health Sciences Library. Four benchmark universities (TU, UAB, PITT, Utah) also offer Safari Tech Books Online, but UofL does not.

II. Periodical Collection

UofL currently subscribes to databases with full-text access to thousands of engineering and science journals. According to Web of Science, listed below are the 30 most frequently used journals (since 2013) on the topic of bioengineering:

Advanced Drug Delivery Reviews
Advanced Materials
Biomacromolecules
Biomaterials
Biosensors & Bioelectronics
Cellulose
Chemical Society Reviews
Clinical Neurophysiology
Electroanalysis
Journal of Environmental Management
Journal of Hazardous Material
Journal of the American Chemical Society
LAB on a Chip
Nanotoxicology
Nature
Nature Biotechnology
Nature Chemistry
Nature Communications

Electrophoresis	*Nature Materials*
Environmental Science & Technology	*Nature Reviews Drug Discovery*
International Journal of Biological Macromolecules	*Science*
Journal of Biological Engineering	*Scientific Reports*
Journal of Biomedical Material Research	*Trac-Trends in Analytical Chemistry*
Journal of Controlled Release	*Water Research*

UofL has full-text access to all of these highly cited journals except *LAB on a Chip* which has been added to our desired purchase list. The most recent 18 months of *Nanotoxicology* are embargoed, but most of the other publications are available from at least 1995 to the present.

III. Databases

UofL and benchmark institution Bioengineering LibGuides and Databases AtoZ lists were reviewed to identify the most prevalent online resources in bioengineering, biomedical, engineering and other sciences. All seven institutions feature links to CAS SciFinder, CINAHL, Cochrane Library, Compendex, Embase, IEEE Xplore, MEDLINE, PubMed, ScienceDirect, Springer Journals and Wiley Online Library. The majority, including UofL, also have AccessMedicine, ACM Digital Library, Current Protocols, Engineering Village, Handbook of Neural Engineering (online) and Web of Science.

The following online resources are not available at UofL but are listed on the websites of at least four of the six benchmarks:

- Scopus
- Annual Reviews
- ASM Handbooks
- ASTM Digital Library (UofL has only one of seven titles, *Journal of Testing and Evaluation*)

SERVICES

I. Document Delivery

Books and periodicals not held by the UofL Libraries are identified through online databases and the online union catalog, WorldCat, which includes more than 32 million records describing materials owned by libraries around the world. Materials are obtained through the traditional Interlibrary Loan (ILL) service, and supplemented by the University Libraries participation in KUDZU, a consortium of major university libraries in the southeastern United States.

II. Research Assistance

Each library within the University of Louisville Libraries offers instruction programs designed to meet the needs of its researchers. Ekstrom Library provides research assistance via in-person appointments, email, telephone, and online chat to help faculty and students locate specific data, business information, and bibliographic citations.

STAFFING

According to most recent data available from ARL, UofL's library staff to student ratio is below that of the three benchmark universities (UIC, PITT, and Utah), but also better than three benchmarks (TU, UAB, USCD). On an absolute basis, however, UofL library staffing is below all but the University of Alabama at Birmingham.

	Library Staff	Full-Time Students	Ratio Staff : FT Students
FY 2015-2016			
University of Louisville	111	17,125	1:154
Temple University	140	34,450	1:246
University of Alabama at Birmingham	73	18,333	1:251
University of California – San Diego	150	32,906	1:219
University of Illinois at Chicago	142	17,319	1:122
University of Pittsburgh	252	26,783	1:106
University of Utah	236	26,911	1:114

Sources: FY 2015-16, ARL Annual Library Statistics

Ekstrom Library does not currently have a librarian with an advanced degree in science or engineering assigned to the STEM disciplines, but hopes to fill the vacant position early in 2018.

CONCLUSION

University of Louisville Libraries' resources appear adequate to support the proposed Master of Science in Bioengineering, especially given that UofL Libraries currently support a Master of Engineering degree for students with an undergraduate degree in bioengineering. This review shows, however, that there are definite opportunities for Ekstrom Library to strengthen its support of such programs, particularly with regard to online resources like Scopus, Annual Reviews, ASM Handbooks Online, ASTM Digital Library, and Safari Tech Books Online, as well as filling the vacant STEM librarian position.

Appendix C

Course Descriptions

BE 524 Labview for Engineering
Description: This course will introduce students to an intermediate level of LabVIEW (Laboratory Virtual Instrument Engineering Workbench) available from National Instruments (Austin, TX). LabVIEW is the worldwide industry standard graphical programming environment for developing data acquisition, instrument control, and industrial automation software. Students will explore core programming fundamentals common to all programming languages by using LabVIEW software to develop independent programs and data acquisition solutions using a combination of LabVIEW, data acquisition hardware, and standard test instrumentation hardware.

BE 540 Machine Learning in Medicine
Description: This course covers: 1) The fundamentals of medical data, 2) the application of machine learning models and algorithms to medicine, 3) learning from data and classification of disorders, and 4) overview of health data, collection with sensors, body area networks, brain image data and other publicly available medical applications data. Students will learn about machine learning applications to real world medical data through examples and reading papers. Students are expected to work on a team project and write technical reports.

BE 542 Medical Image Computing
Description: This course covers: 1) The fundamentals of 2-D and 3-D image computing, 2) the application of image computing algorithms to medical images, 3) enhancement and restoration of 2-D and 3-D medical data, and 4) fundamentals of machine vision and medical data visualization. Students will learn image restoration, computer vision and visualization techniques with applications to medical data through examples and reading papers. Students are expected to work on a team project and write technical reports.

BE 552 Tissue Engineering
Description: Prerequisite: CHEM 341, BE 354, BE 359, BE 450. Design, development and clinical application of tissue engineered components, including blood vessels, bone, cartilage, pancreas, liver and skin, for use in the human body.

BE 581 Advanced CAD and Manufacturing
Description: Prerequisite: Graduate level standing in Bioengineering program. An introduction to the engineering design and manufacturing processes for bioengineering applications with an emphasis on the use of modern computer-based analysis, design and presentation tools as well as manufacturing techniques such as casting, machining, forming and assembly for polymer and metal-based materials.

BE 600 Modeling of Biological Phenomena
Description: Prerequisite: Graduate/Professional Standing in Bioengineering or Consent of Instructor. An advanced course in bioengineering topics not covered by regularly scheduled courses.

BE 601 Bioengineering Seminar
Description: Current research topics in the field of translational bioengineering will be presented and discussed. Sessions will include guest speakers, student presentations on research projects with interaction and feedback from students and faculty, and critical discussion of scientific literature.

BE 605 Tissue and Molecular Biology Techniques

Description: Prerequisite: BE 452 or BE 453. Introduces students to techniques used in tissue and molecular Biology laboratories including cell and tissue culture, cell assays, cell and tissue imaging techniques, sterilization techniques, capillary electrophoresis and western blotting.

BE 611 Cardiovascular Dynamics I
Description: Prerequisite: Graduate/professional standing in bioengineering. Pre- or Co-Requisite: BE 621. Review basic cardiovascular physiology. Application of basic engineering principles, including electrical and mechanical analog models to describe cardiovascular function and data acquisition and analysis techniques to develop medical devices and instrumentation.

BE 621 Bioinstrumentation
Description: Prerequisite: Graduate/Professional Standing, BE 354 or equivalent and BE 322 or equivalent/consent of instructor. Analysis and design of Bioinstrumentation. Basic circuitry, electronics and laboratory techniques including sensors, transducers, biopotentials, amplifiers, measurement and safety.

BE 630 Biomechanical Computer Modeling & Simulation of Human Movement
Description: Prerequisite: Graduate/professional standing; BE 354 or equivalent. Development and application of musculoskeletal computer modeling and simulation techniques to analyze human movement biomechanics.

BE 639 Injury Biomechanics
Description: Prerequisite: ME 649 or BE 354 or equivalent, or permission of the instructor. Note: Crosslisted with ME 639. Application of mechanics to the study of human injury. Response of the human body to injurious conditions. Injury tolerance of the human body. Applications to child abuse, transportation safety and the medico-legal environment.

BE 640 Computational Methods for Medical Image Analysis
Description: Prerequisite: BE 420. This course covers the theory of stochastic and geometric models of medical imaging, including spatial interaction models, intensity models, and geometric shape models. The emphasis is on understanding the underlying mathematics in a practical sense.

BE 650 Advanced Biomaterials
Description: Prerequisite: BE 450 or consent of instructor. Advanced topics on the use of biomaterials, and their performance, in reconstructive surgery. Specifically skin, nerve, bone, and soft tissue regeneration utilized for burn patients, cancer patients, and trauma patients.

BE 653 Nanoscale Bioengineering
Description: Prerequisite: BE 453. Discuss the approaches and techniques in designing, building, characterizing and using biomedical applications, including, interrogation of cellular systems, drug delivery systems, therapeutic systems and uses in tissue engineering applications.

BE 654 Advanced Physiology for Engineers
Description: Prerequisite: BE 354. This course provides an in-depth view of the fundamental principles of how biochemistry and physiology are integrated. Emphasis is placed on the physiologic mechanisms for feedback control of physiologic function in humans.

BE 658 Rehabilitation Engineering and Assistive Technology

Description: Prerequisite: ME 649 or BE 354 or equivalent or permission of instructor. Note : Crosslisted with ME 658. Introduction to rehabilitation engineering and assistive technology. Medical aspects of disability, assistive technology applications and current rehabilitation research.

BE 680 Bio- Micro- Electro- Mechanical Systems
Description: Prerequisite: Graduate/professional standing and ECE 543 or instructor's permission. Application of microtechnology principles to the biomedical field in areas that include tissue engineering, lab-on-a-chip, biosensors, drug delivery, etc. Application-specific criteria supporting the need for miniaturization.

BE 683 Artificial Organs
Description: Prerequisite: Graduate/professional standing in bioengineeing and BE 450. Bioengineering design of artificial organ replacement systems and their clinical usage. Commercially available systems analyzed for mass transfer efficiency; biomechanics and hemodynamics; and size and efficiency of the device.

BE 691 Bioengineering Non-Thesis Design/Research Project
Description: Prerequisite: Graduate/professional standing in bioengineering. Bioengineering design or research project involving a literature search, planning, design, fabrication, experimentation, analysis, and technical report writing under a faculty member's guidance.

BE 695 Research Design and Methods
Description: Topics include the structure of scientific journal papers and proposals, development of specific aims, formulation of hypotheses, types of study design/research methodologies and their appropriate application, data management, data analysis strategies, interpretation and communication of research findings, critique of the scientific literature, and responsible conduct in research.

BE 698 Bioengineering MS Thesis
Description: Prerequisite: Graduate/Professional standing in bioengineering. Original design or research activity in a bioengineering discipline, under the direction of a faculty member. A written thesis must be presented to a faculty committee and orally defended.

BIOC 680 BioMEMS Systems
Description: Prerequisite: BIOC 645 and BIOC 647 or equivalents. This course examines techniques used to characterize biomolecules and their interactions including surface plasmon resonance, equilibrium dialysis, microcalorimetry, analytical ultracentrifugation, dynamic light scattering and absorption fluorescence and circular dichroism spectroscopies.

BIOC 668 Molecular Biology
Description: Prerequisite: BIOC 645 and 647, or consent of instructor. Note: Cross-listed with BIOL 668. Molecular aspects of the structure and function of cells with emphasis on mechanisms and regulation of gene expression.

BIOC 611 Biochemical and Molecular Methods
Description: Prerequisite: Concurrent BIOC 645 or equivalent. An introduction to modern biochemical and molecular biology methods in lecture and laboratory format. Methods covered include RNA isolation, preparative and cytpnockownsquantitative PCR, cloning and sequencing, transfection and reporter gene analysis, western bolts, use of siRNA okdowns, cytiommunoflourescence, and enzyme characterization.

CECS 622 Simulation and Modeling of Discrete Systems

Description: Prerequisite: Probability & Statistics for Engineers (IE 360). Engineering design of simulation languages and simulators, discrete stochastic systems, issues in large scale simulation studies and engineering evaluation methods.

CECS 624 Advanced Simulation
Description: Selected advanced topics in computer and software architectures, algorithms and models in simulation.

CECS 627 Digital Image Processing
Description: Prerequisite: CECS 506 or ECE 420 or faculty consent. A course that surveys basic concepts in image processing and pattern recognition. Topics included are: contrast and edge enhancement, histogram modification, image segmentation, feature extraction, statistical classifiers. Design problems involving computer implementation of algorithms are used extensively.

CECS 641/ECE 641 Medical Imaging Systems
Description: Prerequisite: ECE 618 or ECE 555. Focuses on the foundations of modern medical imaging. Topics include: X-ray generation and X-ray/tissue interactions, projection X-ray imaging,image reconstruction from projections, X-ray CT, MRI, nuclear medicine, SPECT, PET and Ultrasound.

CECS 643/ECE 643 Introduction to Biomedical Computing
Description: Covers various aspects of modern tools of biocomputing in its broad sense; hardware and software issues are covered. Topics include: Super and high performance computer architecture, high bandwidth networking, wireless computing, visualization, and software engineering in medicine. Topics also include computer-assistance interventions, imaging, parallel programming, database design and query, as applied to life, medical, and biomedical sciences.

CECS 660 Introduction to Bioinformatics
Description: Prerequisite: CECS 302 or CECS 503. Covers the current state of the art programs designed for sequence alignment, database searching, RNA structure prediction, microarray, sequence analysis, gene prediction, repeat detection, and protein folding prediction. A detailed analysis of the algorithms behind each of these will be explored. The algorithmic techniques discussed will include dynamic programming, hidden Markov models, finite state automata, grammars, Karlin-Altschul statistics and Bayesian statistics.

CHE 686 Chemical Engineering Analysis
Description: Mathematical modeling of chemical engineering phenomena leading to total and partial differential equations requiring solution by use of series, transforms, and digital computer techniques. Applications to design and analysis of chemical engineering processes.

ECE 543 Micro-fabrication and MEMS
Description: Prerequisite: Senior Standing. Microfabrication techniques including cleanroom technology, lithography, thermal oxidation, diffusion, ion implantation, film deposition, etching, micromachining, wafer-level bonding/polishing, and packaging yield. Microtechnology measurement and analysis techniques. Process simulation. CAD device-layout. MEMS (microelectromechanical systems) and microelectric technology and applications. Material issues for MEMS/microelectronics.

ECE 544 Micro-fabrication and MEMS Laboratory

Description: Prerequisite/Co-requisite: ECE 543. Laboratory to illustrate microfabrication processes, semiconductor measurement techniques, MEMS microstructure fabrication, and MEMS testing. Cleanroom activity required.