Report of the Indiana University Bloomington Engineering Task Force

December 29, 2014

Contents

Executive Summary

Indiana University is the only one of the 62 AAU universities that does not have any type of engineering program. As our society and economy have become far more technological, and as the scientific and technological emphases of IU Bloomington have evolved and matured, Indiana University Bloomington can no longer fulfill its mission to its students, faculty, state, and nation without engineering. Having engineering at IU Bloomington is vital for economic development in Indiana; this was emphasized recently in a study by the Battelle Technology Partnership Practice about economic development in southwest central Indiana that was funded by the Lilly Endowment. Having engineering also is crucial to realizing the full potential of a broad spectrum of ongoing research and education at IU Bloomington, and to recruiting excellent students and faculty to IU.

A large amount of engineering and engineering-related work goes on at IU Bloomington. Over 100 faculty members, research scientists and post-docs in biology, business, chemistry, environmental sciences, informatics and computing, law, optometry, physics, psychological and brain sciences, public health and additional disciplines have engineering degrees. Many of these faculty and their students do engineering-related research, including in the School of Informatics and Computing, which is one of the nation's largest computing schools. Adding an engineering program would strengthen the current research programs of IU's faculty members and students, and would provide a very strong base for new IU Bloomington engineering faculty and students to build upon and collaborate with.

In addition, the excellent strengths of the IU Bloomington campus in areas beyond science and technology offer considerable advantages and opportunities to the establishment of engineering degrees and research programs on the campus. These include the campus leadership in: allied professional schools including IU Bloomington's highly ranked schools of business, law, and public and environmental affairs; IU Bloomington's leadership in international experiences for students, foreign languages, and global and international studies; and topics that link technology and society that draw upon IU Bloomington's great legacy of strength in the humanities and social sciences. An engineering program also can utilize IU's outstanding supercomputing and cyberinfrastructure resources.

Establishing a new engineering program ab initio also offers some very special opportunities. It allows the program to build in crucial components that have become highly important in recent years or decades, but are considerably harder to retrofit into existing engineering programs. These include: multidisciplinarity, both within and beyond engineering disciplines; creating a culture and program design that intentionally enhances student and faculty diversity; an educational orientation towards building and design; an educational design that facilitates international experiences; a research and education orientation that incorporates modern information technology areas such as intelligent systems, big data and user experience; and a research and educational orientation that considers the interplay between technology and society.

We propose that IU Bloomington build an engineering program around areas of engineering that share the following characteristics:

- They build upon the campus research strengths in areas of science and technology;

- They focus on smaller scale, often mobile, often personal/consumer technologies and devices as opposed to engineering that involves large-scale infrastructure and addresses massive structures, plants or systems;
- They incorporate modern information technology approaches including big data, computational modeling, intelligent systems, and user interface design;
- They incorporate design principles that make use of synergies in hardware and software, possibly guided by implementations observed in living systems.

We suggest that the engineering program initially focus on six overlapping areas that share these characteristics: bioengineering; computer engineering; cyber-physical systems; environmental engineering; molecular and nanoscale engineering; and neuro-engineering. A number of engineering and science topics underlie and are common to many of these areas and will be foundational to the program including: sensors, detectors and instrumentation; mobile computing devices and computing hardware; signal processing; control theory; information theory; intelligent systems; big data; computational modeling; and user interface design.

We propose to commence IU Bloomington Engineering with primary emphasis on two degree programs: a B.S. in Engineering, and a Ph.D. in Engineering. A Ph.D. degree is essential to allow faculty to partner with students in their research, and to attract appropriate faculty. One Ph.D. with multiple tracks will supply both the breadth and the agility that we desire, and allow us to deliver a program that permits various specializations with a moderately small faculty. A B.S. degree is essential to achieve the economic development goal of the program, and to fully integrate engineering into the fabric and student culture of IU Bloomington. It also allows us to take advantage of the marvelous opportunities inherent in creating an engineering undergraduate program from scratch. We also propose to create an M.S. in Engineering, although resources may not allow us to concentrate on this immediately. This degree will provide the potential for combined B.S./M.S. programs as well as offering the degree to employees of regional companies. As time goes on, undergraduate and graduate engineering minors or certificate programs also could be of great interest to undergraduates majoring in STEM fields or in business.

We expect that the program initially will require 20-25 new, dedicated engineering faculty members. This number is based upon sufficient teaching coverage, and sufficient depth and breadth of research areas. In addition, we anticipate that the program will have a fairly large number of affiliated appointments from current IU faculty in related fields. These faculty members will play a key role in helping to develop the program as the core faculty are being hired, and would continue to be involved in undergraduate education and graduate student supervision on an ongoing basis. The program also will require adequate student assistant, staff, classroom and laboratory support resources. The program should be configured so that it encourages and facilitates broad collaborations with faculty from all the STEM and professional units that it interacts with in teaching and research, while also being closely affiliated with an existing school or college from which it can get advocacy as well as crucial shared services in areas including faculty hiring, career services, development, and grant support.

We propose that IU Bloomington take a unique approach to hiring many of the new engineering faculty, which will have the advantages of accelerating the pace of hiring, assuring outstanding quality hires, augmenting the ability of new faculty to become engaged quickly in excellent research and education at IU, and increasing the recognition of the new engineering program. This is to invite engineering faculty to apply to IU Bloomington in clusters of two to four faculty, in partnership with an identified group of current IU faculty, and with this entire group of prospective and current faculty focused on starting a new research and education center at IU Bloomington. In conjunction, we hope that IU Bloomington will be able to attract and/or create a significant pool of research funds that can augment standard startup packages and allow an attractive center-level package to be available to each center that is started in this way. Faculty recruiting for these hires would entail not only the normal consideration of each individual candidate, but also broad consideration of the center-scale proposal. Areas for the centers could be any within the proposed scope of the engineering program, with the expectation that they also include collaboration with existing science and technology programs at IU, and strong encouragement to include consideration of societal, business, legal and/or other issues that would lead to collaboration beyond STEM disciplines.

To maintain the current momentum and respond to external demand for an engineering program in a timely manner, it is imperative that IU Bloomington launch the program, with an initial cohort of faculty and enrolled students, in fall 2016. This requires that IU Bloomington begin hiring new engineering faculty in the 2015-16 academic year, or sooner if possible. It also requires that affiliated engineering faculty members are appointed and design the new degree programs during 2015 so that they can be submitted to the Indiana Commission on Higher Education by early 2016. This will allow the new engineering faculty to immediately have enrolled students, while still allowing them to shape the courses and degrees as they evolve.

Section 1: Motivation for Creating an Engineering Program at IU Bloomington

Indiana University is the only one of the 62 AAU universities (60 in the U.S.) that does not have any type of engineering program. Historically, among the two public AAU universities in Indiana, engineering has been confined to Purdue. There is, however, no statutory requirement for this. Furthermore, as our society and economy have become far more technological, and as the scientific and technological emphases of IU Bloomington have evolved and matured, Indiana University Bloomington (IUB) can no longer fulfill its mission to its students, faculty, state, and nation without engineering. There are three major reasons for this which we expand upon immediately below:

1) Having engineering at IU Bloomington is vital for economic development in Indiana.
2) Having engineering is crucial to realizing the full potential of a broad spectrum of ongoing research and education at IU Bloomington.
3) Having engineering is important to recruiting excellent students and faculty to IU Bloomington.

Economic Development in Indiana. The current and future national and international economy demands that all major universities contribute to economic development in at least three ways: producing graduates who are educated to become part of the technological and business workforce; engaging in partnerships with industry and government around technology and business issues; and contributing to the vitality of the economy through technology transfer. A recent study (dated June 2014, released Nov. 2014) funded by the Lilly Endowment and prepared by the Battelle Technology Partnership Practice, entitled "Strategic Plan for Economic and Community Prosperity in Southwest Central Indiana" highlights this need. It recommends, "*Expand and/or develop IU-Bloomington offerings in applied engineering, applied technologies, science, and systems engineering design and development areas, working in consultation with industry partners and NSWC Crane.*" (NSWC Crane is the Naval Surface Warfare Center located in Crane, Indiana 50 miles southwest of Bloomington.)

It expands upon this recommendation: "*A key concern among many of the SWC Indiana's regional clusters is their ability to innovate, increase their productivity, and in certain instances move up the value chain within their clusters. A related issue voiced by industry leaders is the lack of engineering expertise in the region. While most companies and organizations in the region requiring engineering talent have relationships with either Purdue University or other regional engineering schools (typically by hiring graduates), the distance often limits potential further interactions and partnerships. It was also cited that the lack of any engineering or applied technology "connection point" with IU Bloomington makes it more difficult for regional manufacturers to find avenues in which to engage the University. An opportunity exists to launch an exploratory dialog between industry leaders within key SWC Indiana clusters, NSWC Crane, and the leadership of IU-Bloomington to explore the possibilities of bridging this current gap in educational programming, talent generation, and applied research/technical assistance within the region*."

This recommendation is strongly echoed by major industry proximate to IU Bloomington. In addition to NSWC Crane, which employs over 3,000 naval personnel and thousands of contractors including over

2,000 scientists, engineers, and technicians, this includes Cummins and Cook Group. Cummins is a company of approximately 48,000 employees worldwide headquartered in Columbus, IN (36 miles east of Bloomington) that designs, manufactures, distributes, and services diesel and natural gas engines and related technologies. The Cook Group is a group of companies, headquartered in Bloomington and employing about 9,000 people worldwide, which primarily manufacture medical devices. More information on these companies is found in Appendix B.

Augmenting and Enhancing Existing IU Bloomington Strengths. Although IU Bloomington does not offer engineering degrees, a large amount of engineering and engineering-related work goes on at the campus. Over 100 faculty members, research scientists and post-docs as well as many graduate students have engineering degrees. Many of these people are doing engineering-related research in areas of biology, biochemistry, chemistry, environmental sciences, informatics and computing, optometry, physics, psychological and brain sciences and additional disciplines. In many cases, their work is limited by not having engineering students and faculty with whom they can collaborate. Adding an engineering program would strengthen the current research programs of these faculty members and allow them to pursue broader research and funding opportunities and attract additional students. Correspondingly, engineering faculty members at IU Bloomington would have a very strong base of engineering-related science to build upon and collaborate with, as well as relevant work in business, law, and other fields. These collaborations would contribute significantly to undergraduate and graduate engineering education as well as engineering research. A brief list of current engineering-related strengths at IU Bloomington is contained in Section 2 and a fuller summary is provided in Appendix A.

Stature of IU – Attracting the Best Faculty and Students. Faculty and students consider the overall reputation of a university as well as reputation of the specific department or school when deciding whether to attend a university. Many of the leading measures that are used to assess the reputations of universities are highly influenced by scientific and technical publications, funding, awards, and employment impact. IU Bloomington currently is hindered in these rankings by not having engineering, regardless of the quality of the programs that it does have. Building a high quality engineering program would, over time, strengthen all of the factors that are considered in these rankings and thus help the entire university attract the most talented students and faculty.

Special Opportunities in Forming a New Engineering Program. Establishing a new engineering program ab initio also offers some very special opportunities. In particular, it allows the program to build in crucial components that have become highly important in recent years or decades, but are considerably harder to retrofit into existing programs. These include: multidisciplinarity, both within and beyond engineering disciplines; creating a culture and program design that intentionally enhances student and faculty diversity; an educational orientation towards building and design; an educational design that facilitates international experiences; a research and education orientation that incorporates modern information technology areas such as intelligent systems, big data and user experience; and a research and educational orientation that considers the interplay between technology and society and draws upon IU Bloomington's great strengths in the social sciences and humanities. These opportunities are expanded upon in Section 3 of this report.

Section 2: IU Bloomington Strengths Relevant to Engineering

In spite of not having engineering departments or degrees, there is a large amount of engineering-related research and many engineering-trained faculty members at IU Bloomington. This situation has become far more pronounced in the last 15 years, as IU Bloomington has evolved from having a Department of Computer Science with under 25 faculty, to a School of Informatics and Computing (including computer science) which is one of the largest and broadest in the nation, with nearly 90 tenure track faculty members in Bloomington. Overall, IU Bloomington has over 60 tenure track faculty members with one or more degrees in engineering, with the largest numbers in the School of Informatics and Computing, the Kelley School of Business, and the School of Public and Environmental Affairs.

Appendix A gives a summary of the leading engineering-related research in 16 academic departments and schools at IU Bloomington. A brief list of these units and the leading areas of emphasis in each that overlaps with engineering follows:

- ***Astronomy***: design and testing of detectors for astronomical observation and development of calibration and data processing algorithms.
- ***Biochemistry***: virology (including virus assembly and packaging), self-healing systems, and molecular motors.
- ***Biology***: microscopy and imaging, virus assembly and packaging, gene regulation and signaling, and bioinformatics.
- ***Chemistry***: instrument design for precise measurement of molecules, design of functional materials at multiple length scales, and use of chemical techniques to study biological systems.
- ***Geology***: fossil fuel geochemistry and energy resources, modeling of aquatic and atmospheric chemistry, and physical and chemical hydrology.
- ***Kelley School of Business***: management science, project management, information systems, supply chain management, operations management, and entrepreneurship.
- ***Mathematics***: partial differential equations, theoretical sensor networks, signal processing and dynamical systems.
- ***Maurer School of Law***: patent law, legal aspects of venture capital financing and entrepreneurship, cybersecurity and information law and policy.
- ***Optometry***: light tissue interaction, biomechanics of anterior eye surface, design and development of instruments and equipment for vision research and patient care, imaging techniques.
- ***Physics***: detector design and fast trigger algorithms, precision measurement, condensed matter and materials, biophysics and biocomplexity, design and construction of instrumentation.
- ***Psychological and Brain Sciences***: complex networks, molecular and cognitive neuroscience, behavioral informatics and wearable sensors, epigenetic robotics, decision sciences, and big data analytics.
- ***School of Informatics and Computing***: high performance computing architecture and applications, computer networking, robotics, intelligent systems/computer vision, health

informatics, bioinformatics, computer security and privacy, computer architecture, complex networks and systems, and computational photography.

- ***School of Public and Environmental Affairs, environmental science***: environmental chemistry, atmospheric chemistry, microbial biotechnology, hydrology, and environmental modeling.
- ***School of Public Health, environmental health***: solid and wastewater treatment, pesticide use in rural locations, pathogenic virulence resulting from anthropogenic activities, dose-response modeling of toxicological substances, and infrastructure development to optimize human health potential.
- ***Speech and Hearing Sciences***: vocal imaging, acoustics, and biophysics.
- ***Statistics***: network science, machine learning, modeling and parameter estimation, and stochastic simulation and optimization.

In addition, the excellent strengths of the IU Bloomington campus in areas beyond science and technology offer considerable advantages and opportunities to the establishment of engineering degrees and research programs on the campus. A few leading examples include:

- ***Study abroad***: Indiana University Bloomington ranks tenth nationwide among more than 1,000 U.S. universities in the overall number of students studying abroad, and has ranked in the top 10 for the past four years and in the top 20 for the past two decades. IU Bloomington's large network of international partnerships provides an excellent base for designing study abroad into an engineering undergraduate curriculum, and for research partnerships.
- ***Foreign languages***: In conjunction, IU Bloomington offers more foreign languages than any other U.S. university, providing an excellent educational resource for students.
- ***Global and International Studies***: This newly-formed school ties very well into the international dimensions and issues in modern engineering education and research.
- ***The Vincent and Elinor Ostrom Workshop in Political Theory and Policy Analysis***: Co-founded in 1973 by Nobel laureate Elinor Ostrom, the "Workshop" has a significant emphasis on sustainable resource management and improving human understanding of combined social and ecological systems, which offer clear opportunities for interaction with an engineering program.
- ***History and Philosophy of Science***: This excellent department at IU Bloomington has many potential ties to engineering research.
- ***Kelley School of Business***: IU Bloomington's excellent business school is ranked #8 in the US for undergraduate business education, #3 for entrepreneurship, #9 for production and operations management by and #21 for MBA education by *U.S. News & World Report*. It will be very attractive for engineering majors at IU Bloomington to consider either a dual major with business or an MBA following the B.S in engineering.
- ***Jacobs School of Music***: IU Bloomington's music school in consistently ranked first or second in the nation (alternating with Julliard). Music is a common dual major for engineering students, so the presence of an outstanding music school is an attraction. The School also offers and undergraduate major in recording arts that prepares students for careers as sound and audio engineers.

- ***Maurer School of Law***: IU Bloomington's law school is one of the nation's top ten public law schools according to *U.S. News & World Report*, and its intellectual property law program is ranked in the top 25. This will create an attractive combination for some engineering students.
- ***School of Art and Design***: The proposed new IU Bloomington School of Art and Design will strengthen IU Bloomington's already fine programs in design and will be a natural partner in the engineering program's educational and research focus on designing and building physical objects.

The university also recently has launched two major activities that span STEM and other disciplines and will provide important opportunities for interaction with the engineering program. The Network Science Institute unites 100+ researchers at IU toward further scientific understanding the complex networked systems of our world. It draws upon new approaches in mapping, representing, visualizing, modeling, and analyzing diverse complex networks across levels and disciplines, and upon expertise from disciplines including biology, computer science, informatics, information science, medicine (many areas), psychological and brain sciences, political science, sociology and many more. The Center of Excellence for Women and Technology encourages and promotes the technology and computing-related interests of IU women students, faculty and staff from all disciplines and areas of the Bloomington campus. Both are expected to have close ties with an IU Bloomington engineering program.

IU's internationally renowned University Information Technology Services organization also offers two distinct advantages to an IU Bloomington engineering program. First, IU provides some of the most powerful academic supercomputing resources in the nation to its faculty and students free of charge. These resources will provide excellent support for computational modeling research and education in engineering. Second, IU's Global Research Network Operations Center, whose staff of over 80 people provides network engineering and software systems support to some of the world's most advanced research and education networks including Internet2, is a natural partner for education and research in computer and network engineering.

The Indiana University School of Medicine, the nation's second-largest medical school, has a variety of research programs that will be natural partners to an IU Bloomington engineering program, particularly in areas of bioengineering and neuro-engineering. Centers and institutes in the School of Medicine that provide these opportunities include the Center of Computational Biology and Bioinformatics, the Center for Medical Genomics, the Center for Neuroimaging, the Center for Structural Biology, the Indiana Institute for Biomedical Imaging Sciences, and the Stark Neurosciences Research Institute. There already exists a strong history and tradition of collaboration between the School of Medicine and IU Bloomington scientists in many of these areas and programs. A hub for this collaboration is the Indiana Clinical and Translational Sciences Center directed by Dr. Anantha Shekhar of the IU School of Medicine.

Finally, the School of Engineering and Technology at the Indiana University Purdue University Indianapolis (IUPUI) campus has indicated a strong interest in partnering with a new engineering program at IU Bloomington. This would allow the program to build upon the existing strengths, resources and interests of both campuses. The engineering school at IUPUI currently offers Ph.D.'s in biomedical engineering, electrical and computer engineering, and mechanical engineering as "extensions" of programs at Purdue University. There is considerable interest in collaborating with the new engineering program to offer tracks of a Ph.D. in engineering in these fields through IU. All of the Ph.D. programs in engineering at IUPUI have a strong computational component. For example, electrical and computing engineering has significant extramurally funded research related to signal and image processing, information and control systems, intelligent sensing, and applications of big data. Electrical and computer engineering and mechanical engineering have substantial extramural funding related to nanoscale engineering with applications to advanced manufacturing, as well as to energy and medicine. Mechanical engineering has extramural funding related to experimentally supported, multi-scale, thermo-mechanical topology optimization methods and metal additive manufacturing (3-D printing), and high-performance computing for modeling engine combustion. These programs include collaborations with the IU School of Medicine in areas such as bone regeneration and medical imaging. Thus the fit with the foci of the proposed IU Bloomington engineering program is very good.

Section 3: Recommendations Related to the Charge to the Engineering Task Force

Preamble – opportunities related to establishing an engineering program ab initio: A significant upside of being one of the very few AAU schools not to have an engineering program is that one can design a new program from the start with important objectives in mind that existing programs often have had to reverse engineer. These opportunities include:

- **Adaptability/Agility**: These words encompass two related opportunities: the ability to design an engineering program that has few boundaries and can adapt as new engineering challenges arise, and the opportunity to design a program with significant focus on engineering at the personalized or consumer level with the more adaptable technologies and devices that involves.
- **Intelligence**: Big data, computational modeling, intelligent systems, user interfaces, and related topics have become increasingly important in engineering practice, and have emerged as topics that should be a foundational part of engineering education and research. A new program has the opportunity to make these topics core to the curriculum and the expertise of the faculty.
- **Multidisciplinarity**: The lines between historically separate engineering disciplines (e.g. mechanical, electrical, computer, and bioengineering) have blurred considerably if not disappeared. Construction of a new engineering program allows the formulation of curriculum and research that builds upon the integration of engineering disciplines which historically were considered to be separate.
- **Diversity**: Engineering and science education in the U.S., and the industries and professional workforce that utilize these fields, continues to be hindered by the relatively low participation of women and under-represented minorities, and the limitations that this places on bringing diversity of thought and experience to engineering practice. Construction of a new engineering program provides an excellent opportunity to intentionally design a program in a way that engages the interest of a diverse set of participants, in terms of demographics (gender, race, etc.) as well as diversity of personality types and mindsets. Achieving this aim will include building upon known principles for success in diversity in STEM fields such as creating an educational culture and environment that is inclusive and promotes success of all participants, socially relevant curriculum and research, and a diversity of faculty role models.
- **Curricular Flexibility**: The ABET 2000 requirements introduced a greatly increased level of flexibility into accredited engineering curricula. It is difficult to take full advantage of this flexibility when one has a longstanding curriculum and changes it incrementally. Designing a new engineering undergraduate major with the ABET 2000 requirements in mind opens exciting opportunities for innovation and breadth in the curriculum, such as the full integration of modern information technology topics, opportunities for international experiences that don’t delay graduation, and many others. This is explored further in section 3.2.2.

Section 3.1: Suggested Areas of Emphasis in an IU Bloomington Engineering Program

We suggest that IU Bloomington build its engineering program around areas of engineering that share the following characteristics:

- They build upon the campus research strengths in areas of science and technology mentioned in Section 2 and Appendix A, from informatics and computing, biology, chemistry, physics, psychological and brains sciences, environmental science and health, and other fields;
- They focus on smaller scale, often mobile, often personal/consumer technologies and devices as opposed to engineering that involves large-scale infrastructure and addresses massive structures, plants or systems;
- They incorporate modern information technology approaches including big data, computational modeling, intelligent systems, and user interface design;
- They incorporate design principles that make use of synergies in hardware and software, possibly guided by implementations observed in living systems.

Preliminary discussions with major potential employers including those in Indiana have strongly supported these foci.

We suggest that the engineering program initially focus on six overlapping areas that share the four characteristics mentioned above: bioengineering; computer engineering; cyber-physical systems; environmental engineering; molecular and nanoscale engineering; and neuro-engineering. A number of engineering and science topics underlie and are common to many of these areas and will be foundational to the program including:

- sensors, detectors and instrumentation
- mobile computing devices and computing hardware
- signal processing
- control theory
- information theory
- intelligent systems
- big data
- computational modeling
- user interface design

Following is a brief description of the types of research that would be natural fits within each of the six suggested initial focal areas. The specific research topics will evolve as faculty are hired, but the topics mentioned below, which have strong linkage to existing research at IU Bloomington, will help guide hiring.

Bioengineering: Bioengineering is a very broad field and we suggest a focused approach that is consistent with the principles and foundational areas mentioned above. Promising areas that can be built on IU Bloomington's existing strengths include: biomolecular engineering, which includes nucleic acid and protein engineering as well as synthetic biology and aims to provide engineering tools involved with DNA, RNA, proteins and small molecules; bioelectronic engineering, which includes bioimaging and sensor devices used in biomedicine and healthcare, and focuses on the interface between biological systems that produce biochemical and optical signals and electronic systems which deal with electrical signals; biomechanical engineering, especially involving biomechanical devices and systems, such as the design and implementation of microfluidic and nanotechnical devices; and biotechnology with specific applications in toxicity and environmental science. These areas build upon the base of a large, successful bioinformatics program at IU Bloomington in the School of Informatics and Computing and the biology department, as well as research in biochemistry, chemistry, environmental science, optometry, public health, speech and hearing sciences, and physics, and research at IUPUI in biomedical engineering and the School of Medicine.

Computer engineering: The computer engineering cluster will build upon research in the School of Informatics and Computing, including the Center for Research in Extreme Scale Technologies (CREST). CREST and the School have a number of faculty members with strong backgrounds in engineering that will be able to serve as a core around which to bring in new faculty hires and jump start the computer engineering program. Key topics that are likely candidates for initial deployment of the program include computer architecture for systems, processor cores, and instruction sets; computer network technology, topology, switches, and protocols; power and energy for large-scale computing systems; embedded computing and control; resilience through fault tolerance, error detection, isolation, and correction, system reconfiguration; and robotics. One promising aggregate area that builds upon the primary focus of CREST is extreme-scale computer architecture. This research entails dramatically improving efficiency and scalability through hardware structures that unify processor core mechanisms with lightweight message protocols and processor-in-memory functionality. A second potential area is autonomous mobile computing platforms. This area merges the fields of high performance computing, artificial intelligence, sensors and actuators, and graph processing to deliver independence of operation in a physical context.

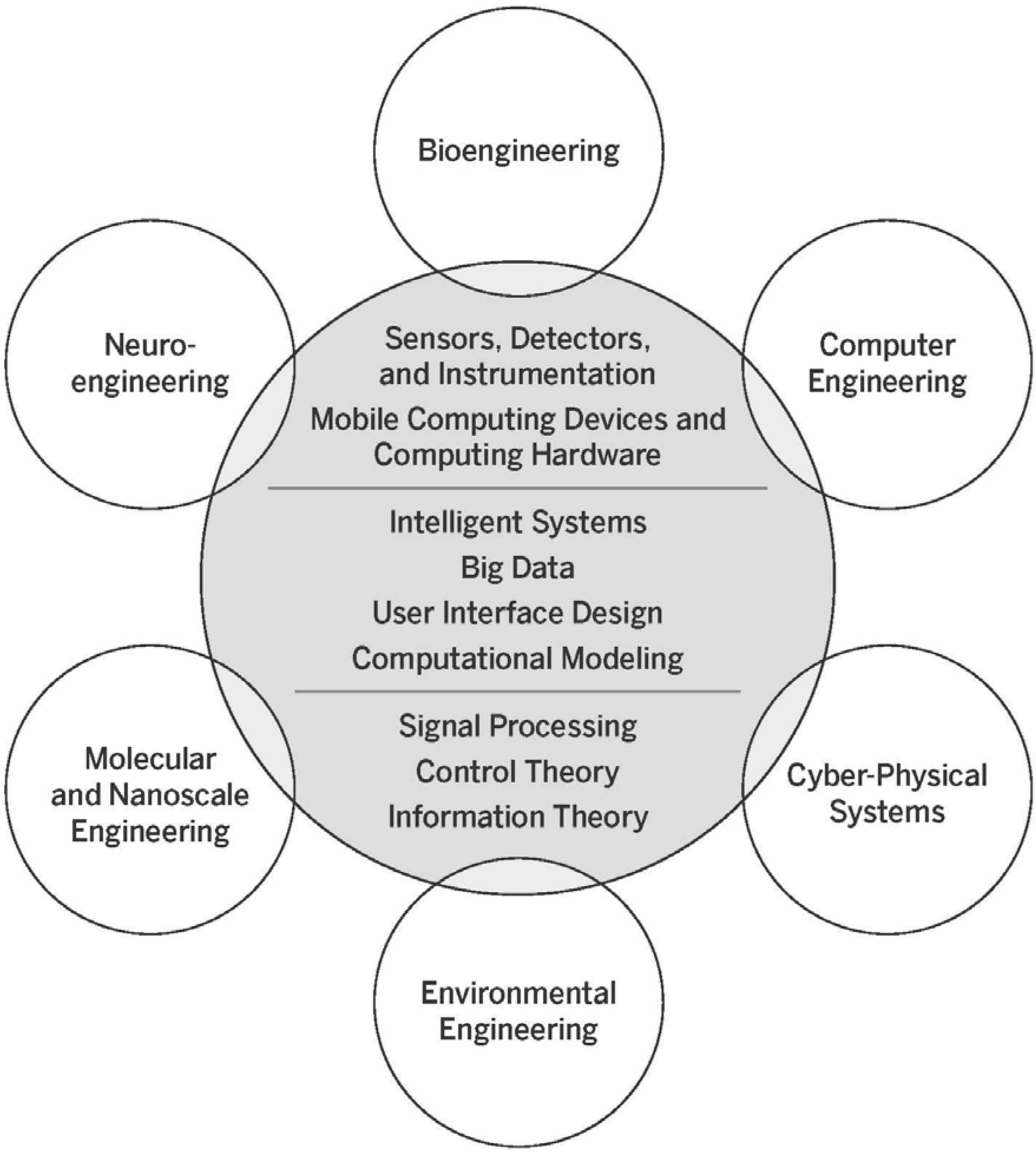
Cyber-physical systems: The broad integration of information technology and the sciences is a recognized field, often referred to as cyber-physical systems. As defined by the National Science Foundation, "*Cyber-physical systems are 'smart' networked systems that are engineered to sense and interact with the physical world, and to support real-time performance in safety-critical systems. The joint behavior of the 'cyber' and 'physical' elements of the system is critical. Computing, control, sensing and networking are deeply integrated throughout the system, and the actions of components and systems must be carefully orchestrated.*" Research and education within cyber-physical systems requires local expertise in designing and building instruments. This expertise already is well represented in the departments of physics and chemistry, and the School of Optometry, which have a tradition of designing and constructing state-of-the-art instrumentation, as well as the School of Informatics and Computing, in research in robotics and personal health devices. Current applications span many areas including personalized health devices, robotics, and sensor networks. Existing campus strengths overlap with numerous subfields within cyber-physical systems including: complex networks and systems; design of detectors and detector systems; intelligent sensing and complex environments; neural and neural-inspired systems; real-time processor design; and self-assembly and development. These draw upon ongoing research in biology, biochemistry, chemistry, cognitive science, informatics and computing, mathematics, optometry, physics, psychological and brain sciences, public health, public and environmental affairs, and statistics. This broad expertise and research provides a natural path to initiate an IU Bloomington program in cyber-physical systems.

Environmental engineering: The environmental science faculty in the School of Public and Environmental Affairs are currently involved in a number of physical, chemical, and biological research areas that would be strengthened by having an environmental engineering program. Approximately one third of the active research faculty members have degrees in engineering. Current research themes that could sponsor graduate students in environmental engineering include atmospheric chemistry, aquatic chemistry, surface water hydrology and environmental water quality modeling, bioremediation, bioengineering, and applied microbiology. A potential area of further expansion is the development of sensors for rapid measurement of aqueous- and gas-phase pollutants including development of drones to measure 3-D concentration gradients and fluxes. This could be developed in conjunction with the School of Informatics and Computing and the department of chemistry. In addition, development of research activities in the field of life cycle analysis has been discussed at SPEA. This research theme would involve both an engineering approach and utilize the existing cross-discipline expertise at SPEA in economics and cost-benefit analysis.

Molecular and nanoscale engineering: Building from the precision of molecular and nanoscale constructs, new materials and responsive/adaptive platforms can be designed to translate advances from physics, chemistry, biology, and computational sciences into functional tools. The scope of molecular and nanoscale engineering is broad. Promising areas for emphasis that connect to existing strengths at IU Bloomington include engineering quantum technologies and nanomanufacturing via self-assembly. These areas will help develop future technologies with potential to surmount Moore's law and facilitate the manufacturing of chemical and biological sensors and networks, spintronic transistors, opto-electronic switches, and higher density storage platforms. These areas build on existing strengths in self-assembly (chemistry and biochemistry), molecular and nanoscale design (chemistry, physics, and biochemistry), materials analysis (chemistry and physics), and simulation (School of Informatics and Computing, mathematics, physics, and chemistry).

Neuro-engineering: Neural engineers solve design problems at the interface of living neural tissue and non-living constructs, creating technology to measure, repair or replicate the brain's function. This cluster will build upon research expertise in psychological and brain sciences and the program in neuroscience as well as computer science and mathematics. The creation of micro-scale devices that couple the nervous system to physical systems, such as devices that may detect impending seizures, can lead to new insights into cognitive development as well as computations that underlie memory systems. Advances in this research area promise to break barriers to current understanding of the brain at all scales of analyses (from molecular to populations of neurons to whole organism behavior) and provides an unprecedented opportunity to revolutionize diagnosis and treatment of brain disorders. Advances in neuro-technology will create new physical replacement parts for the damaged nervous systems, new devices to read out brain function and 'smart machines' to accomplish tasks that are now performed by human experts. Indiana University Bloomington, with its expertise in molecular, cognitive, and behavioral neuroscience and in psychopathology and advances in IT enabled research across disciplines is well poised to be a major contributor in this field. Note that this proposed cluster will integrate well with the cyber-physical systems cluster.

Figure 1: Proposed IU Bloomington Engineering Areas of Emphasis and Underlying Topics



Section 3.2: Suggested Initial Academic Degree Programs, and their Distinctiveness

We propose to commence IU Bloomington Engineering with primary emphasis on two degree programs: a B.S. in Engineering, and a Ph.D. in Engineering. The rationale for these choices is straightforward:

- A Ph.D. degree is essential to allow faculty to partner with students in their research, and hence, to attract appropriate faculty. One Ph.D. with multiple tracks will supply both the breadth and the agility that we desire, and allow us to manage a program that permits various specializations with a moderately small faculty.
- A B.S. degree is essential to achieve the primary economic development goal of the program, supplying engineers to the regional workforce, and to fully integrate engineering into the fabric and student culture of IU Bloomington. It also allows us to take advantage of the marvelous opportunities inherent in creating an engineering undergraduate program from scratch.

We also propose to create an M.S. in Engineering, although resources may not allow us to concentrate on this immediately. This degree will provide the potential for combined B.S./M.S. programs at IU Bloomington as well as offering the degree to employees of regional companies. Undergraduate and graduate engineering minors or certificate programs also could be of great interest to undergraduates majoring in STEM fields or in business. We feel that including these programs initially is not realistic due to the limited faculty resources, but they would be desirable to consider after a few years.

Section 3.2.1: Ph.D. in Engineering

The Ph.D. in Engineering will be constructed to include tracks related to each of the featured areas in the program, tentatively the six areas described in Section 3.1. The Ph.D. program initially will be designed for students who already have an M.S. degree. Thus it will build either on students who have received an M.S. in an engineering field from another university, or who receive an M.S. in a science field at IU Bloomington that provides most of the requisite preparation for their advanced engineering coursework and dissertation. For example, an M.S. in computer science from the School of Informatics and Computing with an emphasis on computer systems and architecture, or an M.S. in Environmental Science from the School of Public and Environmental Affairs, may provide the foundation for the computer engineering or environmental engineering Ph.D. tracks, respectively.

Each Ph.D. track will include advanced coursework drawn both from the engineering program and the affiliated science and technology departments/schools that are partners in these areas. As is standard, all Ph.D. students will be fully supported as long as they make satisfactory progress towards their degree, through teaching assistantships (AIs in IU terminology), research assistantships, or fellowships. Given the post-M.S. nature of the program, most of the Ph.D. students' time will be spent conducting research.

There is potential interest from the IUPUI School of Engineering and Technology to offer Ph.D. degrees to its Indianapolis-based students through the IU engineering Ph.D. The number of highly active and well–funded faculty members in IUPUI engineering faculty is at least equal to the initially expected number of engineering faculty at IU Bloomington. Thus, engaging these IUPUI engineering faculty with the new engineering research and graduate education programs would enhance both the quality and depth of these programs. The natural tracks for the IUPUI faculty to participate in would be computer engineering and bioengineering.

Section 3.2.2: B.S. in Engineering

We envision a general engineering B.S. degree that provides a solid foundation in engineering science, engineering design, and engineering projects and practice, and a limited degree of specialization in one of the engineering areas of emphasis previously mentioned. The degree would be accredited under the general criteria of the Engineering Accreditation Commission of ABET, in the ABET category of degrees in "Engineering, General Engineering, Engineering Physics, Engineering Science, and Similarly Named Engineering Programs", but not under an additional set of specialized, discipline-specific criteria. This model is used by excellent engineering B.S. programs at universities that have smaller engineering units such as Dartmouth, Harvard, Harvey Mudd, Smith, and Swarthmore.

In conjunction with its science, mathematics, and engineering elements, we anticipate that the B.S. degree will be distinctive and visionary in a variety of ways:

- *Program built on effective principles for diversity*: The major will be designed around practices that effectively engage and retain a diverse mix of students. These include involving students in research and in team-oriented project courses early in their undergraduate careers, utilizing course materials and service learning options that allow students to see throughout their education how their chosen field benefits society, and providing a culture and environment that welcomes diverse perspectives.
- *Information technology orientation*: The curriculum will include coursework and experience in modern computing and information technology that are important to designing and deploying engineering devices and products. These include big data, computational modeling, intelligent systems, and user experience. Preliminary input from industrial partners strongly advocates for this direction and emphasizes its distinctiveness. The School of Informatics and Computing will be a key partner in providing this educational content.
- *Design/build orientation*: The major will be designed so that students gain experience in engineering design and projects throughout the four-year program. This includes project courses and design experiences at all levels of the curriculum, and encouragement and support for utilizing campus design and fabrication facilities both within and outside of the curriculum. The proposed new IU Bloomington School of Art and Design will be an important partner in this portion of the program.
- *Global orientation*: We will consider whether the curriculum can be designed to permit students to choose a semester-long study-abroad experience and still be on track to follow a normal sequence through the four year program. This would include providing a path through the major that allows mastery of a foreign language. This builds upon IU Bloomington's leadership in study abroad experiences, language instruction, and global and international affairs.
- *Research experiences*: We intend that a hallmark of the program will be undergraduate research experiences for the majors. These experiences are invaluable in the students' education, attractive to employers, and very supportive of the diversity goals of the program.

- *Business, entrepreneurship and intellectual property law*: The major will provide opportunities for coursework in operations management, product management, supply chain management and product development, and/or experience and education in entrepreneurship including relevant aspects of intellectual property law. Both of these directions build upon the Kelley School of Business' leadership and strength in business functional areas and in entrepreneurship, including the undergraduate entrepreneurship certificates that it already offers jointly with many IU Bloomington schools including the School of Informatics and Computing, as well as the Maurer School of Law's patent law offerings available through the school's Center for Intellectual Property Research.
- *Societal context and perspective on engineering*: A crucial element of any modern engineering education is coursework and experience that helps situate engineering in a broader societal and ethical context. These elements will be integrated throughout the program and will allow the major to draw upon expertise from a variety of parts of IU Bloomington, including a number of social science and humanities departments in the College of Arts and Sciences, the social informatics expertise in the School of Informatics and Computing, and legal perspectives from the Maurer School of Law.
- *Pathways to professional degrees*: The curriculum will be designed in ways so that students who prefer these options can efficiently move into graduate education in other professional disciplines such as business or law. This acknowledges the fact that an engineering undergraduate education often is an excellent and necessary step for people seeking careers in areas such as engineering product management, or intellectual property law.

We expect that there will be a receptive audience for the new degree. This is based upon two factors: the innovative design of the degree, and the attractiveness of IU Bloomington particularly to students from Indiana and the Midwest. Many local and regional students have long commented that if IU Bloomington had an engineering program they would have chosen it so that they could take advantage of the breadth of IU Bloomington in so many other fields, and the beauty and heritage of the campus, in conjunction with obtaining an engineering education. These are students who currently do not apply to IU Bloomington, so the major gives IU Bloomington an opportunity to increase undergraduate enrollment if it feels it has the capacity overall, with little or no pull away from existing majors.

Enrollment targets at this stage are at best an educated guess. We would plan for an initial enrollment of 25 students per year, growing to 50-100 students per year within the first 3-4 years. The growth of the informatics major at IU Bloomington, which reached 100 students per year within its first years and 350 students per year in just over ten years, is an interesting although not entirely analogous comparison.

Section 3.2.3: M.S. in Engineering

The M.S.in Engineering will serve several purposes. First, it will allow students to enter the Ph.D. program with just a B.S. in engineering or a related field and take their preliminary graduate coursework at IU Bloomington. Second, it will allow us to offer coordinated B.S./M.S. programs to IU Bloomington undergraduates. This may include programs leading to an M.S. in engineering for students majoring in one of the sciences at IU Bloomington, as well as 4+1 programs for undergraduate engineering majors. Finally, if there is demand from local employers, it will allow us to offer an M.S. in engineering to employees to who already have a B.S.in an engineering or related field.

While it is imperative that we offer the B.S. and Ph.D. in engineering from the outset, it would be acceptable to defer offering the M.S. for 1-2 years until there is a large enough engineering faculty to offer a sufficient set of courses. It also is likely to be necessary to choose one or two of the areas of emphasis as the initial concentrations in the M.S. Bioengineering, computer engineering, and/or cyber-physical systems may be the most likely choices but this will depend heavily on initial faculty hiring.

Section 3.3: Resources Required for an IU Bloomington Engineering Program

This section presents estimates of the faculty, graduate student support, staff, laboratory and classroom, and overall space resources needed to launch the program and sustain it through its first few years. These estimates are highly preliminary and should be considered a rough indication of resource levels.

Section 3.3.1: Faculty

We expect that the program initially will require 20-25 new, dedicated engineering faculty members. This number is based upon two calculations: sufficient teaching coverage, and sufficient depth and breadth of research areas.

For teaching, we assume that research active tenure-line faculty will teach two courses per year; a few will teach less due to particularly large research portfolios and/or administrative duties. These calculations lead to a capacity of a little under 35 courses per year from 20 faculty members, 40+ courses from 25 faculty members. Coupled with some teaching contributions from math, science and technology faculty, 20 engineering faculty members are needed to offer adequate coverage at the B.S. and Ph.D. levels, including regular availability of undergraduate and graduate courses in the areas of emphasis. 25 faculty members would be needed to support an M.S. degree at a reasonable level as well. 20 faculty members likely would permit coverage of at least five of the proposed areas of emphasis with about four faculty members each, 25 faculty would permit coverage of all six areas and/or deeper coverage of a few.

We propose that IU Bloomington take a unique approach to hiring many of the new engineering faculty, which will have the advantages of accelerating the pace of hiring, assuring outstanding quality hires, augmenting the ability of new faculty to become engaged quickly in excellent research and education at

IU, and increasing the recognition of the new engineering program. This is to invite engineering faculty to apply to IU Bloomington in clusters of two to four faculty, in partnership with an identified group of current IU faculty, and with this entire group of prospective and current faculty focused on starting a new research and education center at IU Bloomington. In conjunction, we hope that IU Bloomington will be able to attract and/or create a significant pool of research funds that can augment standard startup packages and allow an attractive center-level package to be available to each center that is started in this way. Faculty recruiting for these hires would entail not only the normal consideration of each individual candidate, but also broad consideration of the center-scale proposal. Areas for the centers could be any within the proposed scope of the engineering program, with the expectation that they also include collaboration with existing science and technology programs at IU Bloomington, and strong encouragement to include consideration of societal, business, legal and/or other issues that would lead to collaboration beyond STEM disciplines. As just one illustrative example, a center based around robotic devices for personalized health-care or elder-care would have the potential to combine all these elements and be distinctive to IU.

Even using this strategy, it still may take three to four years to hire 20-25 new faculty members. We recommend that initial hiring be half to two-thirds at the senior level as building a new program is too heavy of a demand on untenured faculty, and the center approach requires senior leadership. Faculty hires will require ample individual startup packages in addition to the center packages, to help build their laboratories and groups and add to the inducement to join a new program.

We also anticipate that the program would have a fairly large number of affiliated appointments (either adjunct or dual) from faculty currently in science and technology fields including biology, chemistry, computer science, environmental science, informatics, mathematics, physics, psychological and brain sciences, public health, statistics and other disciplines. These faculty members would play a key role in helping to develop the program as the core faculty are being hired, and would continue to play a role in undergraduate education and graduate student supervision on an ongoing basis. Initially it may be wise to limit the number of adjunct and dual appointments to 15-20 to balance the number of dedicated engineering faculty.

Section 3.3.2: Graduate Student Support

Preliminary calculations show that 15-20 associate instructor positions (20 hours/week for Ph.D. students) will be required to support the undergraduate and larger graduate courses in the early years of the program. In addition, we expect that the average faculty member will provide external funding to support about two to three graduate students as research assistants, leading to a total population of about 60 Ph.D. students in by the third or fourth year of the program. In the medium term, the costs of the AIs will be funded by the program through IU's resource centered management budgeting approach, but some initial support from the campus will be required for the AIs.

Section 3.3.3: Staff Support

The positions that will be needed at the outset include the program head's assistant/department manager, a finance/grant specialist, one or two laboratory mangers, an undergraduate advisor/coordinator, and a graduate advisor/coordinator. In addition, it is assumed there will be some leverage from a higher level unit for key areas including career services and development, likely requiring the hiring of an additional career services staff member. Depending on the degree of leverage and combination of duties, budget for five to seven new staff positions seems to be a minimal requirement.

Section 3.3.4: Teaching Laboratories and Classrooms

The educational programs will require a minimum of four or five teaching laboratories that support 25-50 students each, both for specialized courses such as electronic circuits, and for general project and capstone courses. The initial course offerings also will utilize at least three classrooms full time. The campus currently is building several fabrication laboratory facilities (primarily in the School of Informatics and Computing) and the engineering program will lead to the need to expand the capacity of these.

Section 3.3.5: Overall Space

A rough calculation is that at standard IU office and student lab sizes, the personnel mentioned above (including students) require about 10,000 gross square feet (gsf) of space. Teaching laboratories require about 5,000 gsf. Depending on the experimental nature of the faculty research, at least 5,000 gsf of additional space will be required to augment the graduate student spaces with laboratory space. Classroom space could require an additional 3,000 gsf if there is not available capacity on campus and fabrication lab expansion another 2,000 gsf. This leads to a conservative estimate of 25,000 gsf of space to house the program in its early years.

Section 3.4: Structural Considerations for an IU Bloomington Engineering Program

At the outset, we envision a department-sized engineering unit. This leads to at least two immediate issues to consider: where the unit should be placed within the structure of IU Bloomington, and what the unit should be called. This section articulates the leading possibilities and issues to consider for each of these topics.

Section 3.4.1: Placement of the Program

There are two primary objectives that need to be considered in determining the best way to place the engineering program within the structure of the campus:

1) The program should be configured in a way that encourages and facilitates broad collaboration with faculty from all the STEM and professional units that it interacts with in teaching and research. As mentioned above, we expect a significant number of adjunct and dual appointments from other STEM units, and considerable teaching and research partnership from units. The structure should enable this collaboration to be natural and smooth, including

supporting appropriate revenue allocation models when students and instructors come from different units.

2) The program would benefit strongly from being closely affiliated with an existing school or college to benefit from advocacy by that dean (particularly in initial hiring), and many shared services that are crucial to its success in areas including career services, development, and grant support. The most natural unit for such an affiliation may be the School of Informatics and Computing but all possibilities should be considered.

The choices for meeting these dual objectives would appear to be either: a) making the new unit a department of an existing school/college with very clear mechanisms for broad campus participation in its programs and governance, or b) creating a free-standing unit with ties to one existing school/college for support services.

Section 3.4.2: Name of the Program

The name of the new unit either could be something generic (e.g. Engineering, or Engineering and Applied Science) or something that indicates the more specialized and modern nature of this unit. It would be attractive to come up with a name that differentiates the unit, both to create identity and excitement, and to differentiate what IU Bloomington is doing from traditional, large colleges of engineering both within Indiana and beyond. Many possibilities for names already have been suggested; two that seem potentially interesting at this time are “Intelligent Systems Engineering” and “Convergent Technologies Engineering”.

Section 3.5: Timetable and Milestones in Creating an IU Bloomington Engineering Program

To maintain the current momentum and respond to external demand for an engineering program in a timely manner, it is imperative that IU Bloomington launch the program, with an initial cohort of faculty and enrolled students, in fall 2016. This will require crucial work in faculty hiring and design and approval of new degree programs in the interim. Initial space for the program will be required by fall 2016 and will ramp up to the full estimate of at least 25,000 square feet by about 2018.

Hiring the initial cohort of 20-25 faculty members is likely to take three to four years. We assume that we will begin hiring new engineering faculty in the 2015-16 academic year, or sooner if possible, with the aim of having at least 6-8 dedicated engineering faculty members by fall 2016. They will be augmented by the affiliated faculty described in Section 3.3.1, current IU faculty with engineering interests who have dual or adjunct appointments in the engineering program.

In order to launch degree programs in 2016 along with the first cohort of dedicated faculty, the affiliated engineering faculty will need to design the degree programs in a general manner but to a sufficient extent that they can be submitted to the Indiana Commission on Higher Education before the first new engineering faculty members are on campus. This means that the design occurs in fall 2015 (or earlier in the year if feasible) with submission to ICHE by early 2016. This approach of formulating degrees in advance of hiring faculty was taken in forming the then School of Informatics in 2000. It will free the newly hired engineering faculty members from having to immediately spend their time on degree approval processes, while still allowing them to shape the courses and the degrees as they evolve. As is standard, initial ABET accreditation review of the new BS degree comes after a first cohort of students in the new major has graduated.

Appendix A – Key Programs at IU Bloomington Related to Engineering

- ***Astronomy***: Engineering-related faculty interests in astronomy are in the design and testing of detectors for astronomical observation, and the development of calibration and data processing algorithms. There are two faculty members active in these areas.
- ***Biochemistry***: Biochemistry currently has 10 faculty members, with an equal number of additional affiliated faculty members from chemistry and biology. Research activities that overlap with engineering topics lean heavily toward biophysics. Areas of emphasis include virology (including virus assembly and packaging), self-healing systems, and molecular motors.
- ***Biology***: Around 30 faculty members in biology are active in research areas that overlap with engineering topics. There is research activity in microscopy and imaging (advanced fluorescence, deconvolution and electron microscopy), virus assembly and packaging, environmentally responsive gene regulation and signaling (prokaryotes), eukaryotic gene regulatory networks and signal perception, big data (genomic and bioinformatics), bioenergy (energy generation from microorganisms), and in animal behavior and neuroscience.
- ***Chemistry***: Chemistry has 41 faculty, with many having existing engineering projects or collaborations with engineers. Areas with strong connections to engineering include: analytical chemistry which involves the development of new instruments and methods for precise measurement of chemicals, biomolecules, and materials; materials chemistry which involves the synthesis and study of how function emerges from materials assembled on multiple length scales (molecular, nano, to bulk), with applications in human health, energy and sustainability, detection, and beyond; chemical biology which is the study of biological systems and processes with molecules; and theoretical chemistry which involves the development of new methods and their integration into efficient computation models. Materials chemistry and chemical biology are expected to grow in future years. Individuals in these programs interface with engineering fields such as molecular and nanoscale engineering, material science and engineering, biological and biomedical engineering, chemical engineering, and energy sciences.
- ***Geology***: The department includes approximately 26 faculty and scientists actively involved in research in the areas of atmospheric sciences, biogeochemistry, economic geology, geobiology, geophysics and tectonics, hydrogeology, mineralogy, and stratigraphy. Engineering-related research done by members of the department includes study of fossil fuel geochemistry and energy resources, modeling of aquatic and atmospheric chemistry, and physical and chemical hydrology.
- ***Kelley School of Business***: There are 18 faculty members in the Department of Operations and Decision Technologies who do research and teach courses in various areas of industrial engineering. These areas include project management, operations management, supply chain management, new product development, logistics, lean manufacturing, operations research/management science/data analytics, process optimization, and sustainability.
- ***Mathematics***: There are 17 faculty members in mathematics with ties to engineering. The department has a strong group in partial differential equations (models and analysis of shock waves, turbulence, image processing, fracture mechanics, calculus of variations, climate change and numerical analysis). In the area of signals and systems, there is research activity in

theoretical sensor networks (sensor network localization and generic global rigidity), in robotics (motion planning), cognitive science (logic), and signal processing (machine vision, synthetic aperture radar systems), harmonic analysis and dynamical systems (ergodic theory, dynamical systems, chaos, rigidity), and stochastic processes (statistical physics, probability on groups and graphs).

- ***Maurer School of Law***: The Maurer School of Law's Center for Intellectual Property Research is the likely focal point for connections between the law school and a future engineering program. Several of the Center's faculty are experts in patent law and have degrees in engineering. Others are scholars in the legal aspects of venture capital financing and entrepreneurship. Center personnel have experience in developing and delivering patent law curriculum to undergraduate engineering students, providing undergraduate engineering students with research opportunities, and in collaborating on interdisciplinary research projects. In addition, the law school's extensive expertise in cybersecurity and information law and policy offers another natural point of connection with engineering faculty.
- ***Optometry***: The School of Optometry has a great deal of activity and knowledge in translational engineering and heavily utilizes various disciplines of engineering within its biomedical and optical vision research. Several faculty members also have education in engineering, and/or have developed collaborations in various types of engineering. Specific areas of engineering for which current collaborations exist (at other institutions or campuses), or in which faculty have expressed interest in developing collaborations include: bioengineering such as light tissue interaction; biomechanics (e.g. of the anterior eye surface); design and development of new instruments and equipment for vision research and patient care; optical engineering (e.g. designing new imaging techniques); computer engineering, information processing and software image processing (e.g. transforming and quantifying information).
- ***Physics***: About 28 faculty members in Physics have research interests connecting to engineering. Particular areas of strength are in detector design and fast algorithms (design and construction of detector systems for large particle accelerator experiments, and of fast electronics and fast parallel algorithms for real-time event recognition and trigger systems); precision measurement (development of highly sensitive techniques to perform measurements that exceed existing limits of precision); condensed matter and materials research physics (experimental and theoretical characterization of materials, development and construction of instrumentation for materials testing); biophysics, biomaterial sciences, and biocomplexity (analysis and simulation of biological signal processing and communication mechanisms, development of software for simulation of tissue development, analysis of real and artificial neural networks). There are smaller efforts in accelerator physics, quantum computing and computational physics.
- ***Psychological and Brain Sciences***: The department includes 49 faculty members. Research is focused on understanding how the entire brain-behavior system works – from molecular neuroscience to cognition to the social behavior of groups. Particularly relevant to the engineering initiative are faculty in molecular and cognitive neuroscience (who include two members with engineering backgrounds), and faculty from multiple areas (including cognition, perception, cognitive neuroscience, development, clinical science) using behavioral informatics

approaches and wearable sensors to capture temporally dense multi modal measures of real time behavior. Two faculty members are in active collaboration with robotics research programs (epigenetic robotics). Finally, the department's premier strength across areas of research is in mathematical, computational and large scale data approaches.

- ***School of Informatics and Computing***: The school is one of the largest computing and information school in the nation, with portions on both the Bloomington and IUPUI campuses. The IUB component has about 90 tenure track faculty in computer science, informatics, and information and library science with plans to add 10-15 more in the next few years. It has about 1,200 undergraduate majors in computer science and informatics and about 750 graduate students; the informatics major is the third largest on campus. At IUB the school includes masters in bioinformatics, computer science, human computer interaction design, information science, library science and security informatics as well as Ph.D programs in computer science, informatics and information science. Engineering-related research areas include high performance computing architecture, high performance computing applications, computer networking, robotics, intelligent systems, computer vision, devices side of health informatics, bioinformatics, and computational photography. Other major research strengths include programming languages, computer security, human computer interaction, complex networks and systems, and social informatics.
- ***School of Public and Environmental Affairs, environmental science***: The environmental science group at SPEA includes 13 active research faculty members in the areas of atmospheric chemistry, applied ecology, biogeochemistry and environmental microbiology, environmental toxicology and chemistry, and hydrology and water resources. Seven of these faculty members do engineering-related research, i.e., environmental chemistry, atmospheric chemistry, microbial biotechnology, hydrology, and environmental modeling. Four of the faculty members hold degrees in engineering and one is a licensed professional engineer.
- ***School of Public Health, environmental health***: The Department of Environmental Health within the School of Public Health has faculty with expertise and backgrounds in a number of areas germane to environmental engineering. These include solid and wastewater treatment, pesticide use in rural locations, pathogenic virulence resulting from anthropogenic activities, dose-response modeling of toxicological substances, and infrastructure development to optimize human health potential.
- ***Speech and Hearing Sciences***: The Department of Speech Hearing Sciences has 16 faculty members and conducts research in three areas: language, acoustics and speech. Three faculty have degrees in engineering (electrical engineering, biomedical engineering and biomechanics). Engineering related research includes digital signal-processing and various sensory information-processing areas, and the intelligent analysis of the acoustic environment.
- ***Statistics***: The department includes seven faculty members with research related to engineering. The relevant areas are: network science, machine learning, statistical model selection and parameter estimation, stochastic simulation and optimization, design and analysis of computer experiments.

Appendix B – Key Companies / Employers in the IU Bloomington Region That Will Benefit from an Engineering Program

Naval Surface Warfare Center Crane

Located in Crane, Indiana 50 miles southwest of Bloomington, NSCW Crane is the third largest naval installation in the world. Encompassing 100 square miles, Crane is the third largest employer in the region with over 3,000 Navy employees and thousands more contractors. Crane was founded in 1941 to produce, test and store military weaponry. It has evolved in the past 70+ years to a technology center that employs more than 2,000 scientists, engineers and technicians. Crane's mission is to "*provide acquisition engineering, in-service engineering and technical support for sensors, electronics, electronic warfare, and special warfare weapons. Apply component and system level product and industrial engineering to surface sensors, strategic systems, special warfare devices and electronic warfare systems.*" Crane has evolved from a base that produced and stored ordinance to one that uses the most advanced science and engineering on earth to advance its mission. Crane has survived multiple base realignment initiatives in the last two decades, largely based on innovation driven by science and engineering. There is an almost unlimited demand for engineers at Crane, one that is a constant challenge to meet.

Cummins

Cummins is a company of approximately 48,000 employees worldwide headquartered in Columbus, IN (36 miles east of Bloomington). Cummins is a corporation of complementary business units that design, manufacture, distribute and service diesel and natural gas engines and related technologies, including fuel systems, controls, air handling, filtration, emission solutions and electrical power generation systems. Cummins currently employs approximately 48,000 people worldwide and serves customers in approximately 190 countries and territories through a network of approximately 600 company-owned and independent distributor locations and approximately 6,800 dealer locations. Cummins earned $1.48 billion on sales of $17.3 billion in 2013. The key business units of Cummins include the Cummins Engineer Business, Cummins Power Generation Business, Cummins Components Business and Cummins Distribution Business as well as the Cummins Filtration, Cummins Turbo Technologies, Cummins Emissions Solutions and Cummins Fuel Systems business units.

Cook Group

The Cook Group is comprised of several companies, headquartered in Bloomington and employing about 9,000 people worldwide, which primarily manufacture medical devices. Since 1963, Cook has been a leader in developing health care devices that have improved lives around the world. With sales and marketing offices worldwide, Cook is at the forefront of medical research and product development in minimally invasive medical device technology for diagnostic and therapeutic procedures. The Cook Group's Medical Manufacturing Companies include Cook Inc., Cook Urological Inc., Cook Biotech Inc., Cook Endoscopy, Cook Vascular Inc. and others. Cook Inc. manufactures more than 50,000 individual products sold worldwide. The company is acknowledged as a leading manufacturer of catheters, wire guides, introducer needles and sheaths, stents and stent grafts, embolization coils, intraluminal filters and other minimally invasive devices. Cook Urological has created a comprehensive line of endourological products that reduce patient trauma by eliminating open surgeries. It is recognized worldwide for its innovations in stone management, diagnostic and therapeutic products for the urinary system, and biomaterials for the treatment of urinary incontinence. Cook Biotech develops and manufactures commercial biomaterials from natural tissue sources for use in medical products. The Cook Group also includes two allied manufacturing companies, Cook Polymer Technologies and K-Tube Technologies.

Appendix C – Selected Universities That Have Begun an Engineering Program in Recent Years

Harvard University, School of Engineering and Applied Sciences (became a school in 2007)

Engineering and applied sciences at Harvard changed from being a division (established in 1997) of the Faculty of Arts and Sciences to a school in 2007, in recognition of the renewal and growth engineering and applied sciences had experienced at Harvard. At the undergraduate level, it offers both an A.B. and an S.B. in Engineering Sciences, with the goal of creating students who excel in engineering and applied sciences but also have broad knowledge of other disciplines and wish to connect advances in engineering to society's most challenging problems. At the graduate level, in keeping with the interdisciplinary nature of modern research, it does not have traditional academic departments and does not award graduate degrees by specific research area. Instead, students may work towards a Master of Science, Master of Engineering, and Doctor of Philosophy degree in one of five subjects—Applied Mathematics, Applied Physics, Computer Science, Computational Science & Engineering, and Engineering Sciences.

Smith College, Picker Engineering Program (established 1999)

The Picker Engineering Program is the first engineering degree program at a woman's college in the United States. It includes a B.S. in Engineering Science for students who intend to practice professionally as engineers, a B.A. in Engineering Arts for students who do not intend to practice as engineers but recognize the increasing importance of science in today's world, and a minor in engineering for students who wish to complement their major and supplement their education. The B.S. in Engineering includes a six-course engineering core, a year-long capstone design project course, a two-semester engineering design and professional practice course, five additional engineering electives, and courses in math, science and the liberal arts.

University of California Santa Cruz, Department of Biomolecular Engineering (established 2004)

The Department of Biomolecular Engineering is an interdisciplinary department that combines expertise from biology, mathematics, chemistry, computer science, and engineering to train students and develop technologies to address major problems at the forefront of biomedical and bio-industrial research. The department offers an undergraduate minor and a B.S. degree in bioinformatics, and M.S. and Ph.D. degrees in biomolecular engineering and bioinformatics. The department co-sponsors the B.S. in bioengineering program with the departments of Computer Engineering, Electrical Engineering, and Molecular, Cell, and Developmental (MCD) Biology. The department co-sponsors the Program in Biomedical Science and Engineering, a doctoral training program, with the departments of MCD Biology, Chemistry and Biochemistry, and Micro-biology and Environmental Toxicology.

University of Chicago, Institute of Molecular Engineering (established 2011)

The Institute for Molecular Engineering, established in 2011 by the University of Chicago in partnership with Argonne National Laboratory, is a transformational academic unit exploring the intersection of science and engineering. Building upon the University of Chicago's mission of cross-collaboration and cutting-edge research, the institute will lead science and engineering research and education in new directions, solve technological problems of global significance, and continually inspire creative applications of molecular-level science. It plans to offer a minor program, undergraduate program, and Ph.D. in molecular engineering.

University of Georgia, College of Engineering (established 2012)

The University of Georgia launched a full new engineering college in 2012. The College is using an interdisciplinary approach for preparing students to engage in critical issues through careers in leadership and professional practice, and addresses the challenges facing society with collaborative research in technologies and concepts that will transform Georgia, the nation and the world. It offers B.S. degrees in agricultural engineering, biochemical engineering, biological engineering, civil engineering, computer systems, electrical and electronics engineering, environmental engineering, and mechanical engineering; M.S. degrees in agricultural engineering, biochemical engineering, biological engineering, engineering, and environmental engineering; and Ph.D. degrees in engineering, and biological and agricultural engineering.

Appendix D – Members of the Engineering Task Force

- Esfan Haghverdi, Associate Professor of Computer Science and Associate Dean of Undergraduate Studies, School of Informatics and Computing
- Mark Janis, Professor of Law, Robert A. Lucas Chair of Law, and Director, Center for Intellectual Property Research, Maurer School of Law
- Andrew Lumsdaine, Professor of Computer Science, Director, Center for Research in Extreme Scale Technologies, and Associate Dean of Research, School of Informatics and Computing
- Flynn Picardal, Associate Professor, School of Public and Environmental Affairs
- Rob de Ruyter, Professor and Chair, Department of Physics and former Associate Dean for Research, College of Arts and Sciences
- Bobby Schnabel, Professor of Computer Science and Informatics and Dean, School of Informatics and Computing (task force chair)
- Sara Skrabalak, James H. Rudy Associate Professor and Dean's Fellow, Department of Chemistry, College of Arts and Sciences
- Linda Smith, Distinguished Professor and Chancellor's Professor of Psychological and Brain Sciences and former chair, Department of Psychological and Brain Sciences, College of Arts and Sciences
- Ash Soni, Professor of Operations and Decision Technologies, The John Esther Reese Professor, and Executive Associate Dean for Academic Programs, Kelley School of Business
- Erik Stolterman, Professor of Informatics and Chair of Informatics Division, School of Informatics and Computing

Committee Staff:

- Kelsey Keag, Manager of Communications, School of Informatics and Computing
- Jim Shea, Senior Director of Planning and Communication, School of Informatics and Computing

Appendix E – Charge to the Task Force

1. What areas of engineering should an IU Bloomington engineering program emphasize? What opportunities will this offer for collaboration with existing programs/units at IUB and other campuses of IU?

2. What academic degrees should the engineering program offer, and what is the best starting point for these degrees (Undergraduate or graduate? New degrees or tracks of existing degrees? Correspondence to ABET accreditation?).

3. What programs at other universities serve as the best models for IUB to learn from starting an engineering program, and what are the key lessons learned from them?

4. What resources will be required to start a new engineering program? This includes faculty, staff, facilities and equipment.

5. Where will it make the most sense to house a new engineering program?

6. What rough timetable will be appropriate to begin a new engineering program?