The Development of a Biomedical Engineering Degree Program at a Primarily Undergraduate Institution

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The College of Engineering at Cal Poly has developed a degree granting Biomedical Engineering Program. This structure evolved from the Biomedical Engineering Specialization in the General Engineering Program. This paper describes the approaches we have used to establish this program, and to ensure that it will persist and flourish at the university.

I. Introduction

Although a wide array of existing campus activities supported the Biomedical Engineering Specialization, the prior informal arrangement did not have the unifying organizational structure, nor the dedicated faculty associated with a formal BS degree granting program. The University and the College of Engineering Strategic Plans both identified Biomedical Engineering as a critical emerging technology for the coming decades. It is also recognized as a crucial growth area for the college. The University and the college are prepared to make the changes necessary to meet the identified and articulated needs of industrial partners and our students. Our vision is to create an internationally-recognized, premier undergraduate Biomedical Engineering degree program. The program mission is to educate our students for careers of service, leadership and distinction in biomedical engineering or other fields by using a participatory, learn by doing, "hands-on" laboratory, project and design centered approach.

The program will accomplish this goal by building on the historic strengths of the college at the bachelors level and the individual strengths of participating faculty. The application of engineering to medicine and biology underpins a strong and growing segment of the industrial sector, is the basis for a number of federal conversion efforts and continues to be an area of inherent interest to students. The need for well educated professionals in this interdisciplinary area has become more acute as the technology being applied has become more sophisticated. Evolution in computing, electronics, signal analysis and mechatronic systems have been harbingers of improvement to diagnostic efforts, therapeutic approaches and bioindustrial applications. Studies of biological materials, physiological mechanisms, biochemical kinetics and heat and mass transport in biological systems require engineering expertise. With the advent of research into artificial organs and prosthetic devices, applied medical research and applied biological research has taken on a distinct engineering aspect. The growth of MEMS and nanosystems, each particularly pertinent in the biomedical realm, has further reinforced the role of the engineer in medical and bioengineering application.

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The new Biomedical Engineering Department will provide a complete, in-depth Biomedical Engineering curriculum to students already well grounded in the core undergraduate engineering curriculum. The program highlights an immediate introduction to the major, strong personal interaction with faculty, strong partnerships with industrial participants and a signature laboratory emphasis. It is rooted in the College's historical emphasis on applied research, and in the College's tradition of industrial interaction. Faculty will provide a curriculum that will allow students to pursue applied biomedical engineering in practical, interdisciplinary settings. Students and faculty will be concerned with the design, analysis, integration and operation of engineered materials and engineered systems in biological applications. Participants will also be concerned with the development of techniques, theories and models which further the implementation of new engineered systems and materials in industrial settings, with particular strength in biomaterials / biomechanics and bioinformatics / modeling.

To create the program, we used university/college resources and industrial partnership to accomplish the following aims: 1) Establish the Bioengineering Program within the Bioengineering Department, a fundamental organizational change which will provide the framework and infrastructure to nourish a vital program. 2) Hire two new tenure-track faculty over the next two years, each with interest in a key programmatic area, bringing the total number of dedicated faculty to 4.5 . We also participate in the hiring of faculty by other departments and colleges. 3) Forge particularly strong curricular links to biology, and to bioresource and agricultural engineering. 4) Establish links to other undergraduate engineering degree programs which will provide biomedical engineering emphases for other majors. This will enlarge the talent pool for the bioengineering industry. 5) Create a purposeful adjunct professor and visiting professor program to meet curricular objectives. 6) Establish a core curriculum and develop critical new courses. 7) Create state-of-the-art instructional and research laboratories in two core areas of interest. Our initial foci will be biomechanics/biomaterials and biocomputing/informatics. 8) Further increase student enrollment. 9) Appoint a Program Advisory Board comprised of members from industry, academia, and government. 10) Establish suitable techniques for course and program assessment.

II. Special Program Niche

California Polytechnic State University, San Luis Obispo (Cal Poly) is one of the twenty-three campuses that constitute the California State University System, the nations largest 4-year university system. More than 19,000 students attend this campus, noted for its excellence in Polytechnic areas, engineering, architecture, agriculture, business and science. The primary focus of Cal Poly is undergraduate polytechnic education and the applied terminal masters degree. The hallmark of the Cal Poly engineering education is the "learn by doing" philosophy that emphasizes laboratory experience and industrial participation in the curricula.

Alumni possess an unparalleled combination of analytical skill as well as teaming and laboratory capability. Corporations find that our graduates possess a solid theoretical foundation as well as an appreciation for the application of theory to practice. Cal Poly has an earned reputation for graduating engineers with two feet on the ground and two hands on the problem. The appreciation is fostered by

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the high proportion of laboratory courses in all engineering disciplines. These laboratories provide the hands-on experience that bridges theory to practice.

At this juncture, a wealth of industrial demand, coupled with student and faculty interests, have created an intellectual engine that has outgrown its informal governing structure. Furthermore, the University has been directed to grow and has chosen Biomedical Engineering as one of several focus areas for this growth. The proposed structure for biomedical engineering will provide for the close cooperation and collaboration between engineers, life scientists, and medical doctors required to forge a successful biomedical engineering program. Part of this project involves a collaboration of life scientists and engineers at the University to create a new introductory experience for all science and engineering students.

The Biomedical Engineering program is to be associated with the College of Engineering and will offer baccalaureate degrees in Biomedical Engineering. Because Biomedical Engineering is such a demanding field of study, a traditional four-year degree program will not, in all cases, provide enough time for students to attain the engineering excellence that is expected of Cal Poly graduates. Therefore, the program will have a strong association with the existing 4+1 program, coupling the BS degree to a MS Engineering Degree with a specialization in Biomedical Engineering.

There are academic programs in Bioengineering and Biomedical Engineering at more than 80 universities in the United States alone and many of these have undergraduate as well as graduate programs. The vast majority of these programs are centered on the production of Ph.D.'s, M.D.'s and the generation of *avant garde* research. The need for a Biomedical Engineering program focused on providing bachelors and applied masters graduates to the growing biomedical engineering industry is acute. In addition, the need for a program focused on accomplishing the applied research required to transform laboratory procedure into industrial practice is critical. The program at Cal Poly will fill these needs.

The objectives of the proposed degree program are to satisfy the needs and expectations of primary and secondary stakeholders in engineering education at Cal Poly. The primary stakeholders are:

- the Students Who Desire to Undertake Engineering Education at Cal Poly, SLO,
- the Industries and Business Organizations of the State of California,
- the Faculty and Staff Members Associated with the Biomedical Engineering Program,
- the College of Engineering at Cal Poly-SLO

Needs and Expectations of Engineering Students

Biomedical engineering is an area of inherent interest to students, particularly those underrepresented in the engineering arena. There has been a significant growth in the number of students participating in the Biomedical and Bioengineering options within the General Engineering Program. This is a major component in the growth of the College population.

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Needs and Expectations of California Industries and Businesses
California industries and businesses are at the forefront of the biomedical engineering industry. The industry is resilient, strong, and will expand even further in the coming decades.

Needs and Expectations of the College of Engineering at Cal Poly-SLO
The College of Engineering at Cal Poly-SLO has an established tradition of educating undergraduate engineers who are not only theoretically sound, but who can rapidly integrate into the work force. The college is renown for its capacity to meet the needs of its students, and to meet the needs of California's industry. It is the mission of the college to develop and support programs that will have the uniqueness of Cal Poly education and meet the expectations of primary stakeholders.

Needs and Expectations of Faculty Members
In the past decade, with funds earned through competitive internal and external proposals, the College has been able to hire a number of faculty who have strong backgrounds in the biomedical engineering arena. Some of these faculty members have worked closely with several California industries and have established strong individual ties in their respective areas of specialty. As a result, the faculty members, because of interaction with interested students, are focused on elevating their applied research and scholarly activities beyond the undergraduate level. If such support is not available to the faculty members, it might be difficult to retain and attract faculty members with specialty training in high demand areas.

The Biomedical Engineering Program at Cal Poly will capitalize on the strengths of the engineering program: the reputation for excellence in engineering education, the size of the college, the breadth of polytechnic disciplines at the institution, the depth of the applicant pool, the administrative recognition of the importance of bioengineering and the unique philosophy of *"Learning by Doing"* that is at the heart of the institution. Cal Poly defines excellence in terms of the educational process, we measure our impact by the value added while earning our polytechnic degree. The following attributes distinguish the Cal Poly engineering experience from that of other institutions, and will also characterize the Biomedical Engineering Program.

Faculty Devotion to Teaching. The primary focus of Cal Poly is undergraduate polytechnic education. Effective teaching receives the highest faculty priority while applied research and other forms of professional development enable the faculty to remain on the "cutting edge" of their respective disciplines. Senior faculty expose students to theory juxtaposed with meaningful examples of its application in "real-world" settings.

Industrial Participation in the Curriculum. Integrating the Public and Private Sectors. Cal Poly believes in synthesizing educational institutions, industry, and government into the engineering curriculum. Cal Poly understands that learning is enhanced by the participation of industry. Strong ties with leading corporations, formally incorporated in the curriculum, are essential to preparing young engineers. Industry sponsors personnel exchange programs: loaning accomplished professionals to teach technical classes at the University and allowing faculty experts to work within the company.

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Companies also provide projects for upper division design laboratories, underwrite courses, contribute to senior projects and master's theses, contribute equipment, and participate in strategic policy groups at the Department, College, and University level. St. Jude – Pacesetter, the U. S. Army Institute of Surgical Research, Guidant, Hewlett-Packard and many other associates have and/or will continue to participate with the college.

Early Exposure to Engineering Coursework. Unlike most university programs, Cal Poly students take engineering courses each quarter of enrollment. Students at Cal Poly declare their major at the point of admission, immersing themselves in their chosen discipline early on.

Laboratory Approach to Technical Education. "Learn by Doing" is the Cal Poly credo. Our graduates are accustomed to working in diverse, goal-oriented teams. Laboratories provide the hands-on experience necessary to link theory with practice. Students in every discipline take a large number of laboratory units at both the upper and lower division levels. Cal Poly graduates are not intimidated by laboratory work or laboratory equipment; our students are capable of rolling up their sleeves and doing useful work the first day on the job.

Emphasis on Summer Jobs and Cooperative Internships. Over half of Cal Poly's engineering students participate in a Co-op experience - an engineering internship in the private sector, often with attractive remuneration and significant responsibility. Co-ops generally last from one to two quarters, frequently beginning in the summer months. Co-ops and internships are an excellent tool for companies to contribute to Cal Poly student development. It also provides companies with an opportunity to evaluate a candidate's potential for future employment after graduation. In this year alone, over 400 students will participate in Co-op experiences through positions offered by 260 companies. Eight of the top twenty co-op companies on campus (in terms of 2001-2003 hires) are either biomedical engineering companies or have hired students to work in bioengineering divisions of their companies. The list includes St. Jude, Guidant, AVE, Alcon, Perclose, Baxter, 3M, Gore, Medtronic, Agilent, Amgen, and Genentech.

Capstone Senior Project Experience. The Senior Project at Cal Poly, San Luis Obispo, is a time honored tradition. For over 50 years, the Senior Project has been the culminating undergraduate experience and an excellent segue to industry or further study for each of our students. Requiring independent activity and original thought, the senior project is the logical extension of our hands-on laboratory intensive undergraduate program. In Biomedical Engineering, the senior project has grown into a project based learning experience, and can accommodate large groups of students working on larger and more pertinent projects.

III. Curricular Structure

The Biomedical Engineering curriculum has been designed to satisfy eight specific goals. Student learning objectives that will allow us to meet these goals have been determined. The specific goals of the proposed degree program in Biomedical Engineering are:

(1) To satisfy the ABET accreditation criteria as an engineering program. The BS Degree Program in Biomedical Engineering will seek accreditation through the Accreditation

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Board for Engineering and Technology (ABET), Engineering Accreditation Commission (EAC), at the first accreditation visit scheduled by the college after the creation of the degree granting program.

(2) To provide biomedical engineering students with a thorough understanding of the principles, processes and tools required for the successful design and development of dependable, biomedical engineering components and systems.
(3) To provide all students in the college with an excellent introductory exposure to biomedical engineering / life science, and to provide curricular options for student of all majors who are interested in biomedical engineering.
(4) To educate biomedical engineers with advanced practical knowledge in impacted fields of biomedical engineering so as to support industries of California to meet their needs to design, optimize, and reengineer processes and methods to achieve success in the global arena.
(5) To provide biomedical engineering students with experience in team work and management, preparing them for the role of technical management in the biomedical engineering arena.
(6) To enable biomedical engineering students to take the professional licensing examination in the state of California, per learning objectives (a) through (o), listed below.
(7) To create an environment where motivated faculty can achieve their professional goals while furthering the aspirations of biomedical engineering students.
(8) To provide an undergraduate Biomedical Engineering Curriculum with strong links to the existing 4+1 program MS Engineering, Biomedical Engineering Specialization, and to enrich curricular offerings for the MS program.

To support these goals, the learning objectives for students participating in the program are:

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

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(o) an ability to address the problems associated with the interaction between living and nonliving systems.

The curriculum developed to ensure that these goals are met is listed below. Learning objectives a through o are shown for each course, the level at which each course addresses these objectives is listed as 0,1,2,3 or 4. Four (4) indicates that the course very strongly addresses the goal, 0 that it is not seriously addresses at all.

Table I . Course Objectives Matrix

COURSES	a	b	c	d	E	F	g	h	i	j	k	l	m	n	o
ENGR 110 Introduction to Engineering	2	1	4	2	9	2	2	2	1	1	0	0	0	0	0
BMED 111 Biomedical Engineering (BME) Calculations	4	2	1	1	4	1	2	1	1	0	0	0	0	0	0
BMED 212 Introduction to BME Design	4	2	4	4	4	2	4	2	0	2	2	2	1	0	2
BMED 310 BME Measurements & Analysis	2	4	2	4	4	1	2	0	0	1	4	2	4	4	4
BMED 410 Biomechanics	4	4	2	2	2	1	2	0	1	1	2	2	4	2	2
BMED 420 Biomaterials	2	2	2	2	4	4	2	2	2	2	3	2	4	3	4
BMED 425 BME Transport	4	4	2	2	4	1	2	0	1	1	2	2	4	4	2
BMED 430 Biomedical Modeling	2	2	2	4	2	3	2	2	2	2	4	2	2	4	2
BMED 440 Bioelectronics & Instrumentation	4	4	2	2	4	1	4	0	0	1	4	2	4	4	4
BMED 460 Engineering Physiology	4	4	2	4	2	1	2	0	2	1	2	4	2	3	3
BMED 455 BME Design I	4	4	4	4	4	1	4	3	2	2	1	2	2	1	4
BMED 456 BME Design II	4	4	4	4	4	3	4	3	2	2	1	2	2	1	4
BMED 450 Special Topics in BME	4	2	2	2	2	2	2	0	2	4	2	4	4	3	3
Adviser approved technical electives (300/400 level, 16 units)	4	3	1	1	3	1	1	2	2	2	3	4	4	3	4
Senior Project	3	2	2	4	4	3	4	2	4	2	2	2	3	3	3
Bio 213 and ENGR 213	1	1	0	0	0	0	1	1	1	1	1	0	0	0	0
CHEM 124 General Chemistry	1	2	0	0	1	0	1	0	0	0	1	0	0	0	0
CHEM 125 General Chemistry	1	2	0	0	1	0	1	0	0	0	1	0	0	0	0
ENGL 149 Tech Writing for Engr	0	1	0	4	0	0	4	2	2	2	0	0	0	0	0
MATH 141 Calculus I	1	0	0	0	1	0	0	0	0	0	0	0	4	0	0
MATH 142 Calculus II	1	0	0	0	1	0	0	0	0	0	0	0	4	0	0
MATH 143 Calculus III	1	0	0	0	1	0	0	0	0	0	0	0	4	0	0
MATH 241 Calculus IV	1	0	0	0	1	0	0	0	0	0	0	0	4	0	0
MATH 244 Linear Systems	1	0	0	0	1	0	0	0	0	0	0	0	4	0	0
PHYS 131 General Physics	1	2	0	0	1	0	1	0	0	0	1	0	0	0	0
PHYS 132 General Physics	1	2	0	0	1	0	1	0	0	0	1	0	0	0	0
PHYS 133 General Physics	1	2	0	0	1	0	1	0	0	0	1	0	0	0	0
Math and Science Electives (16)	3	4	0	2	0	0	2	2	0	2	3	4	2	0	0
IME 144 Intro to Design & Mfg	1	1	1	2	0	0	0	0	0	1	3	0	0	0	0
CE 204 Strength of Materials	4	0	0	0	4	0	0	2	0	0	4	0	2	0	0

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CSC 101 Fundamentals of Computer Science *or* CSC 234 C and Unix	1	1	4	1	1	1	2	1	2	1	2	0	0	0	0
EE 201 Electric Circuit Theory	4	0	0	0	4	1	2	0	1	1	1	0	2	0	0
IME 314 Engineering Economics	4	2	3	0	2	2	1	3	2	2	1	1	0	0	0
MATE 210, Materials Engineering	4	3	1	3	2	0	2	0	0	0	2	0	0	0	0
ME 211 Engineering Statics	4	0	0	0	4	1	2	0	1	1	1	0	2	0	0
ME 212 Engineering Dynamics	4	0	0	0	4	1	2	0	1	1	1	0	2	0	0
ME 302 Thermodynamics	4	1	2	1	4	1	2	1	1	1	1	0	3	0	0
ME 341 Fluid Mechanics	4	1	2	1	4	1	2	1	1	1	1	0	3	0	0
GEB Package	0	0	0	1	0	0	2	2	4	1	0	0	0	0	0

The curriculum requirements under the proposed BS Biomedical Engineering degree will meet the general guidelines specified by the Catalog and the College of Engineering. The summary of curriculum requirement guidelines for the degree is as follows. Note, the Biomedical Engineering Degree will require a minimum of 196 units, of which at least 60 units must be at the 300 and 400 level.

Table 2. Curriculum by Content Segments

Required Major Courses (69)	**Units**
MAJOR COURSES	
* = *Courses satisfy General Education and Breadth requirements*.	
ENGR 110 Introduction to Engineering	3
BMED 111 BME Calculations	3
BMED 212 Introduction to BME Design	3
BMED 310 BME Measurement and Analysis	4
BMED 410 Biomechanics	4
BMED 420 Biomaterials	4
BMED 425 BME Transport	4
BMED 430 Biomedical Modeling	4
BMED 440 Bioelectronics and Instrumentation	4
BMED 450 Special Topics in BME	4
BMED 455 BME Design I	4
BMED 456 BME Design II	4
BMED 460 Engineering Physiology	4
Adviser approved technical electives (300/400)	16
Senior Project	4
	69

Support Courses (91)

Bio 213 and ENGR 213 (B2)*	4
CHEM 124 General Chemistry (B.1.a.)*	4
CHEM 125 General Chemistry	4
ENGL 149 Tech Writing for Engineers	4

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MATH 141 Calculus I (B.2.)*	4
MATH 142 Calculus II (B.2.)*	4
MATH 143 Calculus III	4
MATH 241 Calculus IV	4
MATH 244 Linear Systems	4
PHYS 131 General Physics (B.1.a.)*	4
PHYS 132 General Physics	4
PHYS 133 General Physics	4
Math & Science electives	16
CE 204 Strength of Materials	3
CSC 101 Fundamentals of Computer Science *or* CSC 234 C and Unix (F.1.)*	3
EE 201 Electric Circuit Theory	3
IME 314 Engineering Economics	3
MATE 210 Materials Engineering	3
ME 211 Engineering Statics	3
ME 212 Engineering Dynamics	3
ME 302 Thermodynamics	3
ME 341 Fluid Mechanics	3
* = *Courses satisfy General Education and Breadth requirements*.	—
	91

General Education and Breadth (40) (36 Toward Degree)

Area A: Communication	8
ENGL 133/134 Writing and Exposition (A.1.)	4*
SCOM 101/102 Speech (A.2.)	4
(A.3.) in Support Area	0
Area B: Science & Mathematics	0
28 Units are specified in support	
Area C: Arts & Humanities	16
Literature (C.1.)	4
Philosophy: Phil 230/231 (C.2.)	4
Fine and performing arts elective (C.3.)	4
Upper Division (300–400 level) (C.4.)	4
Area D/E: Society and Individual	16
American Experience (D.1.)	4
Political Economy (D.2.)	4
Comparative Social Institutions (D.3.)	4
Self Development (D.4.)	4
	—
GEB in addition to area B	40
Degree Total Units	196

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* These four units are viewed as remedial, and are not counted in the degree program. They can be earned with successful completion of the English Literature and Composition Placement Test.

Faculty Research as Curricular Embellishment

The existing bioengineering specialization in the General Engineering program capitalizes on the strength of the faculty in engineering, science and agriculture. All Biomedical Engineering faculty are active in research. This research underpins curricular development, and provides a solid core of supported senior projects and thesis support for biomedical engineering students. In addition we have curricular and research connections to The College of Agriculture, and its Dairy Products Research Center, and we are linked to the Biology Department through joint curricular efforts and the Environmental Biotechnology Institute. All new faculty were supported during their first year through release time and provided access to the Biomedical Engineering Applied Research Laboratory in the Advanced Technology Laboratory. Current areas of supported work include micromechanics of bone, blunt trauma, durable and robust splinting mechanisms, medical product development and design, constitutive models for stents and leads, microbial adherence and attachment, microbial interaction with materials, biofilm formation, bioelectric signal analysis and medical data analysis. Faculty enrich and enliven the curriculum by bringing timely examples of timeless principles to their classroom. This exposure enables many students to accomplish more meaningful senior projects, and provides an impetus for them to explore graduate school opportunities – at Cal Poly and elsewhere.

Space and Facilities

In addition to the General Engineering Program Office, located in the Engineering College Office Suite, a number of other facilities are or will be available to Biomedical Engineering students.

- Cal Poly has an historical emphasis on laboratory education - laboratory equipment provides the infrastructure of our value added education. The curriculum taken by General Engineering and Biomedical Engineering students is rich in engineering courses which have associated laboratories or activities. Educational resources provided by the State of California are sufficient to maintain adequacy in our programs, these funds do not provide for the margin of excellence we have achieved at Cal Poly. This margin has been won with support from industrial benefactors and through the industry of our faculty.
- The Advanced Technology Laboratory houses the 2500 square foot St. Jude Bioengineering Laboratory. This building is unique at Cal Poly, in that it has been built without state funds – it is characteristic of our new and innovative approach to engineering education manifest in the Biomedical Engineering program. This facility houses a biomechanics and biomaterials characterization laboratory, as well as an Optical and Scanning Electron Microscopy Facility.
- The Keck Engineering Education Research Laboratory is a 4000 square foot facility in the Advanced Technology laboratories which will be used to explore new ways to deliver engineering education. The Bioengineering Lyceum – a speakers series dedicated to biomedical engineering, is held in this facility. Computing infrastructure in this facility is used for the Biomedical Modeling and Simulation effort in the Biomedical Engineering Program.
- Engineering III, a new, state-supported instructional laboratory building for the College of Engineering will be on-line in Fall 2004. This building will contain approximately 2,4000 square feet of instructional laboratory space dedicated to Biomedical Engineering (Biomechanics Instructional Laboratory, Biomaterials Instructional Laboratory, and Biocomputing Instructional

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Laboratory).

- Engineering IV, a new state supported building will be on line in Fall 2005. This facility will have an additional 3500 square feet of instructional laboratory space for Biomedical Engineering, as well as 10,000 square feet dedicated to interdisciplinary student projects. This facility will contain the Biomedical Engineering Realization Laboratory, a simulation and design facility with rapid prototyping capability. The Biomedical Engineering Imaging and Analysis Laboratory with optical Microscopy, Scanning Electron Microscopy and Atomic Force Microscopy and Image Analysis capability.

Key Curricular Links to Biology, and to Bioresource and Agricultural Engineering

The bioengineering working group was instrumental in developing the core engineering life science course (math, chem prereq) and in establishing a life science requirement for all engineers. We have also developed ENGR 213, a course team taught with biology. The engineering portion of this course is taken by all engineering students (1100 students/yr) and is a exposure to biomedical engineering that is closely coordinated with biological topics presented by biology faculty. It is different from biology alone in that it stresses engineering approaches to biological systems as well as a systems approach to biology. We are also developing a bioengineering course to be offered to the general university population. These courses will provide student credit units for department to justify long faculty hiring, the course will provide exposure for bioengineering, the courses will provide linkage to other disciplines. These sequences will build on the common life science experience for all engineers which is team taught by bioengineering faculty and biology faculty – which we hope will whet their appetite further for biomedical engineering exposures.

Key Links to Other Undergraduate Degree Programs

The Biomedical Engineering program is designed to be flexible. Students have sixteen units of science electives as well as sixteen units of engineering electives. This allows students to develop a depth in a particular aspect of Biomedical Engineering, while maintaining a solid underpinning in the breadth of the field. Some student focus in modeling aspects, others in optics, still others in materials. We have avoided creating tracks because of the inherent diversity of the field. Our philosophy has been that artificial boundaries, though they can provide security are often limiting.

Joint undergraduate programs provide an attractive means to provide meaningful biomedical engineering exposure to students in other engineering disciplines, to recruit students to the Biomedical Engineering program and to provide for an infrastructure that will annually provide resources, such as teaching assistantships and laboratory space and equipment. The joint programs will take the form of a "specialization", short three course sequences, which will fit into a student's existing curricula. These sequences will build on the common life science experience for all engineers which is team taught by bioengineering faculty and biology faculty – which we hope will whet their appetite further for biomedical engineering exposures. Among the initial specializations with established engineering programs are Agricultural Engineering, Materials Engineering, Mechanical Engineering, Electrical Engineering and Computer

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Engineering, Students from Chemistry, Physics and Biology will also be encouraged to participate in this program, which will provide a bioengineering flavor to their study.

A Purposeful Adjunct Program to Meet Curricular Objectives

Because of the inherent diversity in biomedical engineering, we do not expect that the dedicated Biomedical Engineering faculty will be able to provide all content desirable in our curriculum. Thus the program will make use of the links we have forged with faculty on campus to deliver these materials. Furthermore, we will formalize relationships with local medical doctors who currently participate in our program by providing project work for our students. We have approached local vascular surgeons, neonatal specialists and orthopedic surgeons who are excited about the prospects of team-teaching in the college curriculum. We also will bring in specialists via digital links, with direct interactive connections to facilities at our corporate and governmental partners. In some cases, particularly with the industrial partners, these services are donated. The program has budgeted roughly two-thirds of a position to supply these units (four to seven courses offered each academic year).

State-of-the-Art Research and Instructional Laboratories

Biomedical Engineering is a demanding interdisciplinary field of study that involves investigation into systems that are inherently non-linear, heterogeneous, and anisotropic. Studies of biological systems require complex instrumentation and sophisticated techniques to obtain reliable data. One of the strengths of the Cal Poly engineering program is the laboratory emphasis in the curriculum. This will continue to be a strong focus of the Cal Poly Bioengineering program at both the graduate and undergraduate levels. As described earlier, these laboratories include: A) Biomaterials Characterization Laboratory. The purpose of this laboratory is to investigate structure-property relationships of biomaterials to include the behavior of biologic tissues. The activities in this laboratory will be related primarily to mechanical and surface properties, such as fatigue and fracture resistance, strength, stiffness, surface free-energy. Equipment needs for this facility include an axial-torsional servohydraulic materials testing system, custom fixturing for materials testing, video-data acquisition equipment, and surface characterization equipment, and advanced microscopy equipment. This laboratory will directly support courses in biomaterials, tissue mechanics, and tribology. Research that will be conducted in this laboratory will relate to hard and soft tissue mechanics, joint mechanics, cardiovascular devices, as well as biomaterials. And B) an Advanced Computational and Simulation Laboratory. The purpose of this laboratory is to support bioinformatics and modeling, as well as computing intensive efforts in every other lab within bioengineering. It provides an environment for coupling of experimentation and theory. The development of powerful predictive models is a critical need that has its basis in sound experimentation and theory. This laboratory will provide UNIX based workstations for advanced computation as well as Pentium based PC's for less CPU intensive work. Additionally, image processing and analysis equipment will be available.

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Program Advisory Board

Because the field of Biomedical engineering is so dynamic, it is crucial that our new program be advised by participants from our corporate partners and our federal partners – as well as academics from other institutions. These partners will provide curricular guidance, help the program to identify potential areas of growth/need, help the program identify resources and participate in programmatic assessment. Current charter board members include representatives from St. Jude, Guidant, Alcon, Advanced Bionics, Stryker, Medtronic, The U.S. Army Surgical Research Institute and Gore.

Techniques for Course and for Program Assessment

Assessment and feedback to the program for improvement, are a crucial component of any academic program. In the context of this program we include a normative assessment scheme, a summative assessment scheme and a provision for benchmarking. Curricular oversight will be provided through the College of Engineering Advising Center, using existing channels, as well as through a portfolio approach. We will participate in the assessment scheme which led to successful outcomes for all of our engineering programs during the last accreditation visit. Our advisory board will also participate in the review process. We will Promote and validate a suite of assessment methods matched to the context-specific learning objectives of individual projects.

Curricular assessment cannot be implemented after-the-fact. Moving forward, our vision is both simple and demanding. We will implement a program of multi-method cross-validation studies that engage every curricular component of this program. The "Questionnaire" approach will be mandatory, refined and continued. It will be augmented by voluntary, investigator-designed, project-specific questionnaires and interview protocols. Portfolio methods will receive an extra measure of emphasis as technology and services make digital, shareable, portfolio records a more practical methodology. Broad based review boards, populated by industrial partners, representatives of concerned federal agencies and academic colleagues at other institutions will review the program.

Student Evaluation of Courses. Students evaluate faculty performance and course design on both a scantron ranking form and an open-ended questionnaire. Results are tallied, with copies reviewed by the professor, department chair, and dean. Non-tenured faculty and lecturers are evaluated by students quarterly; tenured faculty are evaluated at least annually.

Assessment is decidedly iterative! It is dynamic, provisional and perpetual - we are continually making judgements with incomplete information. For this reason we are using many assessment tools simultaneously. Data from many sources, even if incomplete or approximate, is preferable to few measures, however precise.

IV. Summary

This paper describes a nascent Biomedical Engineering Program at a primarily undergraduate institution. The program is developed to maintain flexibility while providing coverage of the breadth of the biomedical

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engineering field. The program strives to maintain particular niches of applied research expertise based on the strengths of faculty. The program will have five full-time faculty, currently three are affiliated with the program. The present faculty have strengths in biomaterials characterization, computer modeling and simulation, biomechanics and product development. The program will seek new faculty with strengths in the biomedical electronics area and in the engineering physiology area. We will maintain full coverage by having a healthy adjunct faculty program within the university and with industrial partners. In this manner, the Biomedical Engineering Program will achieve its aspiration to be an internationally-recognized, premier comprehensive engineering program and satisfy its mission to educate our students for careers of service, leadership and distinction in engineering or other fields by using a participatory, learn by doing, "hands-on" laboratory, project and design centered approach.

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