ACADEMIC SENATE - SANTA BARBARA DIVISION
FACULTY LEGISLATURE

Thursday, January 14, 2021
3:30 p.m.
Via Zoom

ORDER OF BUSINESS

1. Roll Call

2. Announcements by the Chancellor

3. Announcements by the Chair and Others

   UCSB Re-Accreditation in 2023: Linda Adler-Kassner, Associate Dean, Undergraduate Education
   COVID-19 Update: Stuart Feinstein, Professor of Molecular, Cellular, Developmental Biology

4. Special Orders –

   Consent Calendar

   Minutes of the October 22, 2020 meeting (Attachment 1)

5. Reports of Special Committees

6. Reports of Standing Committees

   Committee on Rules, Jurisdiction, and Elections
   Proposed Revisions to the Academic Senate Manual (Attachment 2)
   Bylaw 170. Meetings of the Division
   Bylaw 180. Order of Business

   Graduate Council
   Biological Engineering – Proposal to Establish a Graduate Degree Program and
   Academic Unit (Attachment 3)

7. Petitions of Students – None

8. Unfinished Business

9. University and Faculty Welfare

10. New Business
The Faculty Legislature of the Santa Barbara Division met via videoconference at 3:30 p.m. on Thursday, October 22, 2020, with Chair Susannah Scott presiding. 41 voting members, 4 ex officio members, and other interested parties attended the meeting.

**Announcements by the Chancellor (from the slides presented)**

Thank you to Professor Henning Bohn, Academic Senate Chair from 2010-12 and 2016-20.

Thank you to Chair Susannah Scott and to all of our Senate colleagues. Shared governance is key to our strength and success as we work together to respond to the challenges of COVID-19.

**Transitions**

**UC President Michael V. Drake, M.D.**
Welcome to UC President Michael Drake, former Ohio State President and, previously, Chancellor of UC Irvine and UC Vice President for Health Affairs.

**CCS Dean Gerardo Aldana**
Welcome to College of Creative Studies Dean Gerardo Aldana, Professor of Chicana & Chicano Studies and Anthropology.

Thank you to Acting Dean of Humanities and Fine Arts Mary Hancock.

Thank you to former Anne and Michael Towbes Graduate Dean Carol Genetti for eight years of leadership. We wish her the best in her new role as Vice Provost for Graduate and Postdoctoral Programs at New York University Abu Dhabi. Thank you to Interim Graduate Dean Leila Rupp.

Thank you to Associate Vice Chancellor for Academic Personnel Alison Butler, for more than five years of dedicated and distinguished service overseeing Academic Personnel. Thank you to our Search Advisory Committee, chaired by Professor Tresa Pollock.
Vice Chancellor for Diversity, Equity and Inclusion Belinda Robnett
Welcome to our new Vice Chancellor for Diversity, Equity and Inclusion Belinda Robnett. Professor of Sociology and former Associate Dean for Faculty Development and Diversity in the School of Social Sciences at UC Irvine. Thank you to Search Advisory Committee Co-Chairs Victor Rios and Ingrid Banks, and all of our participating colleagues.

Police Chief Alex Yao
Welcome to Chief of Police Alex Yao, formerly Police Captain at UC Berkeley. Thank you to our Search Advisory Committee, chaired by Vice Chancellor Garry Mac Pherson, and to our Police Advisory Board, co-chaired by Professors Sharon Tettegah and Geoffrey Raymond.

Campus Updates and Highlights

2020 Virtual Commencement, June 13
Special Thanks to Distinguished Alumnus Jack Johnson!

2020 Virtual New Student Convocation, September 29
Vice Chancellor for Diversity, Equity and Inclusion Belinda Robnett was our keynote speaker.

2020 Fall Enrollment Update
- 91,000 freshman applications; 110,000 total
- First-year students: ~5,000 anticipated enrollment
  Admitted statistics:
  - Average GPA: 4.14
  - Average SAT: 1401
  - Underrepresented minorities: 26%
  - First-generation: 31%
- Transfer students: ~2,350
Among our incoming student body, 85% are from California, and 15% from out of state and around the globe.

2020 Fall Enrollment Update
- Currently it looks like we are about 200 short on freshmen overall (mostly non-residents).
- The overall California transfer numbers make up for the slight California shortage of freshmen.
- As of now, we have 250 students who have let us know they will start in Winter. If they show up as planned, we will hit our targets.
2021 U.S. News Rankings
UC Santa Barbara ranked as #6 Public National University by the 2021 U.S. News & World Report.

Among public universities, UC Santa Barbara is ranked:
- No. 5 for Best Colleges for Veterans
- No. 10 for Best Ethnic Diversity
- No. 9 among top Performers on Social Mobility

Race to Justice
Arts and Lectures’ new Race to Justice event series brings leading activists, creatives, and thinkers to confront racism in America, guiding us toward racial equality.

We stand with our Black community, together in solidarity against hate and injustice.

Henley Hall
Henley Hall has been completed and has been opened for operation.

New Classroom Building
Construction is underway for the new classroom building that will increase instructional space by 35%.

Coastal Planning Science Advisory Board
Thank you to Professor John Melack and members of our Coastal Planning Advisory Board, formed to help us study the potential impact of future sea level rise and bluff erosion on our campus and our long-range plan.

Research Ramp-Up
Last year, campus researchers brought in a record $235 million in sponsored research funding (equal to our campus state appropriation). Our faculty have been writing more research proposals; we have 40% more proposals and awards in the past six months than in the prior year.

Thank you to Vice Chancellor for Research Joe Incandela and our administrative colleagues, faculty, and researchers for working together toward a safe and successful research ramp-up.

Roy T. Eddleman Center for Quantum Innovation
UCSB has received a $1.5 million gift from tech businessman Roy Eddleman to establish the Roy T. Eddleman Center for Quantum Innovation, directed by Professors Ania Jayich, David Weld, and Stephen Wilson.
Drs. Jayich and Wilson are also co-PIs of our $25M NSF-funded Quantum Foundry.

**Harold J. Plous Award**  
Assistant Professor Leah Stokes, Political Science, was named the recipient of the 2020-21 Harold J. Plous Memorial Award. She will give her Plous Lecture in the spring.

**Packard Fellowship**  
Professor Elliot Hawkes, Mechanical Engineering, was awarded an $875,000 Packard Fellowship for Science and Engineering.

**New Horizons Prize**  
Postdoctoral researcher Henry Maxfield has been named a winner of the Breakthrough Foundation’s 2021 New Horizons Prize in Fundamental Physics.

**ACS Hach Award for Entrepreneurial Success**  
Professor Craig Hawker, Heeger Chair in Interdisciplinary Science, has been awarded the American Chemical Society’s 2021 Kathryn C. Hach Award for Entrepreneurial Success, for “innovative leadership in creating, developing, and commercializing revolutionary polymer-based therapeutics and personal-care products through multiple successful start-up companies.”

**NSF Convergence Accelerator Grant**  
Professor Krzysztof Janowicz, Geography, is set to lead a multi-university, multidisciplinary team awarded a $5 million NSF Convergence Accelerator grant to build KnowWhereGraph, a large-scale open knowledge graph for use by decision makers in environmental policy, food security, soil health and humanitarian aid.

**Theater and Dance** staged its first 100% Zoom production of the season, *Immortal Longings*, adapted from Shakespeare’s *Julius Caesar* and *Antony and Cleopatra* and directed by Professor Irwin Appel.

Thank you to ALL of our dedicated faculty, students, and staff, who are finding creative and innovative ways to teach, work, conduct research, and serve our community together!

**Planning for Winter Quarter – Class Schedule**  
**For lower division**, we will continue as we did in fall to offer some labs, performance, and field experience courses in a face-to-face format. Traditional lecture courses in the lower division will continue to be given remotely.
For upper division, almost all courses will be remote as well. A small number of lecture courses will be offered in a face-to-face format, as a trial in anticipation of a spring and summer curriculum closer to normal. These will be less than 3% of the curriculum, in terms of the number of available seats in classes. (Accommodations for students who will be taking classes remotely are an important consideration. The general principle is to ensure remote students have a path to timely graduation.)

The schedule of classes for winter also includes about 30 face-to-face graduate courses, 300 seats total.

This class schedule will go live on Monday, October 26.

Responding to COVID-19

Covid-19 Prevention Plan
Mitigating the Spread of COVID-19 on Our Campus

Bioengineering Lab
Special thanks to Professors Stu Feinstein, Carolina Arias, Ken Kosik, Chuck Samuel, Diego Acosta-Alvear, Max Wilson, and many other faculty, graduate students, postdocs, and staff, and to Student Health Executive Director Dr. Vejas Skripkus and our medical team!

#UCSBTogether
The UC Santa Barbara community unites in response to COVID-19

Chancellor’s Coordinating Committee on Budget Strategy
Thank you to our faculty colleagues on the Chancellor’s Coordinating Committee on Budget Strategy, and all those involved in consultation and guidance for our campus community as we address the budgetary challenges arising from the pandemic.

- Co-chaired by Academic Senate Chair and EVC
- Meets every other Tuesday
- Thanks to Susannah and our Senate Council Planning and Budget, chaired by Professor Douglas Steigerwald, and CPB subcommittees:
  - Committee on Academic Planning & Resource Allocation
  - Committee on Capital & Space Planning
  - Committee on Development & Community Relations

Curtailment Proposal
On October 10, President Drake sent a letter to Chancellors and Academic Senate Chair Gauvain to begin consultation on a “Proposed 2020-21 Curtailment Program.”
Feedback is due to UCOP by November 9.

**Isla Vista**
Emergency alert sent last week regarding two clusters of positive COVID-19 cases in privately owned fraternity and sorority houses in IV.

Letter to students sent on Tuesday, and Student Affairs is hosting a meeting this evening. Free COVID-19 testing is available in Isla Vista on Fridays and Saturdays.

**Santa Barbara County Ordinance**
On October 20, the Santa Barbara County Board of Supervisors approved by a 3-2 vote an ordinance that creates administrative fines for violations of the County Health Officer Order pertaining to COVID-19:

- $100 for first violation
- $200 for second violation
- $500 for third and subsequent violations

This ordinance applies to the unincorporated areas of the County only. There will be second reading and adoption of the ordinance on November 10, 2020. It is effective 30 days from adoption.

**Halloween**
Our A.S. Program Board will be hosting virtual events Friday and Saturday nights, October 30 and 31, including a comedy show and a concert featuring different musical artists. Attendance is restricted to UC Santa Barbara students.

A County festival ordinance prohibiting amplified music at residences will be in effect from 6:00 p.m. until 7:00 a.m. Monday, October 26, through Wednesday, November 4.

In addition, Isla Vista Community Services District is partnering with Lucidity Festival to produce “Halloween at Home: Virtually Lucid in Isla Vista,” a community-wide event for Halloween weekend.

Thank you for your leadership, sacrifices, and shared commitment to meeting the challenges of this pandemic period while upholding our mission and keeping our campus community safe and healthy.

**Announcements by the Chair**
Chair Scott reported on Academic Senate transitions and local campus concerns.

- We have two recently-appointed Academic Senate Vice Chairs, Professor Rita Raley (English) as Vice Chair/Secretary, and Professor Melissa Morgan
(Counseling, Clinical, and School Psychology) with a special portfolio for advancing diversity and equity.

- We also have a new Executive Director, Shasta Delp, who is a great point of contact.
- The Academic Senate website was redesigned over the summer. Thank you to Andy Satomi and Vince Nievares, and the whole Academic Affairs Information Technology team.
- We have developed an Academic Senate newsletter with the aim of keeping faculty informed in an efficient way.
- The Academic Senate is involved in all COVID-19 planning meetings.
- The Academic Senate will be ready to respond to any occurrences associated with the upcoming presidential election.
- In light of expected cuts to the University of California budget, we are thinking carefully how to protect the University’s core mission.
- The Committee on Admissions, Enrollment, and Relations with Schools (CAERS) is working to redesign the freshman admissions process as a result of the vote by the UC Regents to discontinue the use of standardized testing in admissions.

Consent Calendar
The minutes of the June 11, 2020 meeting, In Memoriam notices, and 2019-20 Annual Reports were considered for approval.

Motion: To approve the consent calendar. The motion was seconded, and passed with 41 in favor, 0 against, and 1 abstention.

Reports of Standing Committees

Proposal for Changes to Santa Barbara Regulation 95
Faculty Legislature considered the proposed revision to Bylaw 95 regarding the Committee on Diversity and Equity, which added the Vice Chancellor for Diversity, Equity and Inclusion as an ex-officio member. The proposed change was reviewed by the Committee on Rules, Jurisdiction, and Elections, and approved by the Committee on Diversity and Equity.

Motion: To approve the proposed addition to Senate Regulation 95. The motion was seconded, and passed with 37 in favor, 1 against, and 3 abstentions.

Santa Barbara Regulation 335

The Faculty Legislature considered the proposed Regulation 335 regarding the Requirements for the Master of Environmental Data Science (M.E.D.S.). The new graduate program in Environmental Data Science was approved by the Faculty
Legislature in April 2019, and subsequently by the UC President. However, the new regulation governing the M.E.D.S. degree was not reviewed at that time.

The proposed regulation was previously reviewed by the Committee on Rules, Jurisdiction, and Elections.

**Motion:** To approve the proposed addition of Senate Regulation 335. The motion was seconded and passed with 35 in favor, 1 against, and 4 abstentions.

**Proposal to Establish a Terminal Master of Education in School Psychology**

Graduate Council Chair Tamara Afifi provided an introduction to the Proposal to Establish a Master of Education in School Psychology.

The proposal under discussion is for a terminal Master of Education in School Psychology, to be offered by the Department of Counseling, Clinical and School Psychology. The Department of Counseling, Clinical and School Psychology previously offered a terminal M.Ed. in School Psychology from 1991 until 2013. The program has been redesigned and its larger intent is to redress the shortages of school psychologists across California and nationwide by training and credentialing 15-20 students each year. The proposal has a strong emphasis on recruiting and enrolling a diverse population of students. The proposal has been approved by the Graduate Council and endorsed by the Chancellor. The Faculty Legislature has final approval authority for the proposal at the campus level. If approved, the proposal will be forwarded for review by the Coordinating Committee on Graduate Affairs.

**Motion:** To approve the proposed Master of Education in School Psychology. The motion was seconded and approved by 32 in favor, 0 against, and 7 abstentions.

**New Business**

**Proposal for a Mail Ballot: Request for a Memorial from the Santa Barbara Division of the Academic Senate to the Board of Regents**

The Faculty Legislature considered a proposal to hold a mail ballot on a Memorial to the UC Regents regarding the “History of Medicine in California” mural cycle located in Toland Hall on the UC San Francisco’s Parnassus Campus.

Laura Voisin George, graduate student in the Department of History, provided background information for the members. The proposed Memorial would urge the UC Regents to demand that best-practices preservation methods be employed at UCSF for treatment of the New Deal-era “History of Medicine in California” mural cycle by renowned artist Bernard Zakheim, and to commit to their public accessibility.
If approved, a mail ballot would be distributed to all Senate faculty regarding a proposed Memorial to the UC Regents.

**Motion**: To approve the proposed mail ballot. Motion was seconded and passed with 26 in favor, 3 against, and 3 abstentions.

The floor was opened for general comments and discussion. There was a discussion of various matters related to remote instruction, the Office of the President’s proposed curtailment plan, and the flu vaccine mandate. Chair Scott adjourned the meeting at 5:13 p.m.
January 4, 2021

To: Susannah Scott, Divisional Chair
   Academic Senate

From: Don Marolf, Chair
       Committee on Rules, Jurisdiction & Elections

Re: Divisional Senate Manual Revisions: Bylaws 170 and 180

The Senate Manual has not been comprehensively reviewed since 2002. As a result, many Bylaws and Regulations fail to reflect current best practices, a significant number of citations and titles are outdated, and the text is riddled with inconsistencies in style and format. In consultation with the Committee on Rules, Jurisdiction and Elections (RJE) and the Senate Chair, a select group of Senate staff members was charged with conducting a thorough review of the Manual and making recommendations for revision to RJE.

RJE granted preliminary approval of proposed revisions to Divisional Bylaws 170 and 180, which require final approval by the Faculty Legislature. The revisions to Bylaw 170: Meetings of the Division and 180: Order of Business, intend to:

- Clarify the procedures for special and emergency meetings.
- Remove the word “disability” and simply state “absence” for when the Senate Chair is not present.
- Bring Bylaw 180:B:1 in line with current practice for approving minutes.

Cc: Shasta Delp, Executive Director, Academic Senate
170. Meetings of the Division

A. Scheduling of Meetings

1. The President of the Senate or Chair of the Division may call a meeting of the Division at any time during the academic year. Upon the written request of ten members of the Division to the Executive Council, a special meeting of the Division must be called by the Chair, or by the Vice Chair/Secretary in the Chair’s absence or disability, to consider a request for a referendum on an action of the Senate Assembly or to discuss an announced referendum on an action by said Assembly. Upon the written request of twenty-five (25) members on any other matter, a special meeting must be called by the Chair. [See Divisional Legislative Ruling 4.72, Appendix I]

B. Emergency Meetings

2. An emergency meeting of the Division may be called by the Chair of the Division or, in the event of their absence or disability, by the Vice Chair/Secretary. The Call for such a meeting shall be sent to every member of the Division at least two instructional days before the meeting. The order of business shall be that for special meetings. Legislation is not subject to modification at an emergency meeting.

B. Due Notice

For meetings of the Division or the Faculty Legislature, due notice is five calendar days; for emergency meetings, it is at least two instructional days. However, after a holiday or academic recess, only emergency meetings of a legislative agency may occur before the third day of instruction. (Am 11 Feb 71; Am 22 Apr 99)
180. Order of Business

The order of business at all meetings of the Division (where applicable) and the Faculty Legislature is governed by the procedures specified below.

A. Regular Meetings

1. Roll Call (Faculty Legislature only)
2. Minutes
3. Announcements by the President and the Chancellor
4. Announcements by the Chair and others
5. Special Orders
6. Reports of Special Committees
7. Reports of Standing Committees and Faculties
8. Petitions of Students
9. Unfinished business
10. University and Faculty Welfare
11. New Business
   This order of business may be suspended by a vote of two-thirds of the voting members present.

B. Special and Emergency Meetings

1. Minutes: Will be circulated for approval at the next regular meeting. The reading of the minutes may be omitted with the approval of two-thirds of the voting members present.
2. The special business of the occasion.
3. Any other business authorized by unanimous consent of the voting members present.

C. Special Orders

1. Consent Calendar: Items of business deemed non-controversial by the Chair of the Division may be placed under special orders in the Call as a Consent Calendar. [See Divisional Bylaw 185.A]
2. Degree Reports: Reports of degrees are a special order at any meeting to which they are presented.
3. Annual Reports: Annual reports of Standing Committees are a special order for a regular Faculty Legislature meeting.
4. Memorials: A Memorial transmitted to the Division shall constitute a special order for a regular meeting unless a special meeting is called to consider it.
D. Authority in Questions of Order

Questions of order not covered by legislation are governed by Robert's Rules of Order, or Sturgis Standard Code of Parliamentary Procedure, at the option of the agency involved. (Am 11 Feb 71)
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2. The business of the occasion.
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TO:    Susannah Scott, Chair  
       Academic Senate

FROM:  Henry T. Yang  
       Chancellor

RE:     Biological Engineering Program – Proposal to Establish  
        a Graduate Degree Program and Academic Unit

Following the policy and procedures for the Establishment of a Graduate Program Leading to a New or Existing Degree, and the policy and procedures for the Establishment of a New Academic Unit, Graduate Council has forwarded to our offices a proposal to establish a Ph.D. graduate degree program and academic unit in Biological Engineering. The Council seeks administrative review and appropriate actions to follow up.

The proposal was distributed to Carol Genetti, Dean of Graduate Division; Faculty Executive Committees (FECs) of the College of Engineering and the College of Letters and Science; and Council on Planning and Budget (CPB), Undergraduate Council (UgC), Committee on Library, Information and Instructional Resources (CLIIR), and Committee on Research Policy and Procedures (CRPP), for review and comment. The proposals were accompanied by letters of support from Rod Alferness, Dean of the College of Engineering, and Pierre Wiltzius, Dean of the Division of Mathematical, Life and Physical Sciences in the College of Letters and Science. The reviewing agencies were generally supportive of the proposal, although concerns were expressed about the potential budgetary impacts of the COVID-19 pandemic. At its meeting of May 18, 2020, Graduate Council voted unanimously to approve the establishment of the graduate degree program in Biological Engineering, and to endorse the establishment of the academic unit.

Graduate Council approval came with some caveats. It noted that the Senate normally would require that budgetary concerns be fully addressed before approving a new program proposal. However, given the current uncertainties about the budget, Graduate Council decided that its priority was to review the academic curriculum. It concluded that the curriculum and program plans were solid, representing many years of careful work and strategic preparation. It felt that by operating at the intersection of Engineering and the Sciences, and building upon a history of interdisciplinary collaboration, the proposed program would serve as a cornerstone for the campus’s long-standing plan to create a Department of Biological Engineering. Graduate Council noted that existing campus departments in both the College of Engineering and the Division of Mathematical, Life, and Physical Sciences have made significant, strategic investments in anticipation of the formation of the proposed program, especially in the hiring of new faculty. Much of the intellectual infrastructure for the program is already in place.

The Council recommended that the proponents of the program work with the administration on the logistics of the implementation. The Executive Vice Chancellor has consulted with Deans Alferness and Wiltzius, as well as the lead faculty involved in the proposal. They have emphasized that the proposed program leverages existing curricula extensively in an effort to launch the program with the minimum “critical mass” of faculty; growth areas could expand with new electives as new faculty are hired in Engineering and Science departments. There is consensus that the strong proposals should be approved, with the understanding that the Deans would consult with the Executive Vice Chancellor about the final timing of the launch and implementation of the new unit and degree to ensure a successful beginning. He informed the Deans and the initiators that he would endorse the new degree and unit with the proviso that it be implemented only when the campus was confident that the available resources were in place or committed. With that understanding, EVC Marshall endorsed this proposed degree and recommended that I offer final administrative endorsement of the proposed degree program.
I have reviewed all of the material that has been submitted and concur with the Executive Vice Chancellor’s recommendation and offer final administrative endorsement. This proposed degree is an important interdisciplinary opportunity for our campus. With this final administrative endorsement, the proposal for the new degree program is ready to be placed on the Agenda at the next meeting of the Faculty Legislature for final legislative action.

As noted, Graduate Council also endorsed the establishment of a new academic unit, the Biological Engineering Program. Per policy, the administration has final approval authority to establish a new academic unit after the endorsement of the Senate. I concur with Graduate Council and Executive Vice Chancellor Marshall and offer final administrative approval for the establishment of the Biological Engineering Program. It is understood that the establishment of the unit would not be finalized until the academic degree program received final system-wide approval.

cc:  David Marshall
     Toby Lazarowitz
     Shasta Delp
June 24, 2020

To: David Marshall, Executive Vice Chancellor

From: Henning Bohn, Chair, Academic Senate
        Divyakant Agrawal, Chair, Graduate Council

Re: Biological Engineering Program – Proposal to Establish a Graduate Degree Program and Academic Unit

The Academic Senate’s review of the Proposal to Establish a Graduate Degree Program and Academic Unit in Biological Engineering has been completed, up to the point of Faculty Legislature consideration. At its meeting of May 18, 2020, Graduate Council voted unanimously to approve the establishment of the graduate degree program in Biological Engineering, and to endorse the establishment of the academic unit. Per the policy and procedures for the Establishment of a Graduate Program Leading to a New or Existing Degree, we are forwarding for your review and consultation with the Chancellor this proposal.

The science of biology is proving an increasingly deep and inspiring source of new concepts, mechanisms and materials for application across each of the traditional engineering disciplines. In synergistic parallel, the application of novel technologies and concepts emerging from these same engineering disciplines is rapidly advancing the science of biology. These two endeavors, engineering from biology and engineering for biology, comprise the discipline of biological engineering, a relatively new field that combines discoveries in the life sciences with the fundamental principles of engineering in furtherance of both. Application of engineering principles and the quantitative, predictive modeling to the science of biology is revolutionizing understanding of both health and disease. In parallel, improved understanding of the life sciences is providing powerful new innovations in engineering. These advances are ushering in a new era of biology-derived and biology-inspired technologies responsive to a wide range of challenges in manufacturing, agriculture, the environment and, of course, medicine.

The proposed Program and degree, which in terms of both pedagogy and research are at the interface of Engineering and the Sciences, will benefit critically from the strong relationships that already exist between these communities at UCSB. The proposed Program will also ultimately serve as a cornerstone to the campus’s long-range plan of founding a Department of Biological Engineering, which eventually will also include an undergraduate degree. The proposed program heavily leverages significant, recent campus investments in the area of bioengineering. This investment includes the 2017 completion of a state-of-the-art Bioengineering building that is centrally located on campus and that houses both the Center for Bioengineering and the Institute for Collaborative Biotechnologies. Furthermore, existing campus departments in both the College of Engineering and the Division of Mathematical, Life, and Physical Sciences have, in recent years, made significant, strategic investments in anticipation of the formation of the proposed Program, including the hiring of the majority of the faculty members who are participating in this proposal. In fact, the proposal team of twelve faculty members comprises primarily junior faculty members: six of them are at the rank of Assistant Professors and three are Associate
Professors. Many of these faculty members were hired in the anticipation of starting a bioengineering program at UCSB.

The proposal was distributed to Carol Genetti, Dean of Graduate Division; Faculty Executive Committees (FECs) of the College of Engineering and the College of Letters and Science; and Council on Planning and Budget (CPB), Undergraduate Council (UgC), Committee on Library, Information and Instructional Resources (CLIIR), and Committee on Research Policy and Procedures (CRPP), for review and comment. The proposals were accompanied by letters of support from Rod Alferness, Dean of the College of Engineering and Pierre Wiltzius, Dean of the Division of Mathematical, Life and Physical Sciences in the College of Letters and Science. The reviewing agencies are cautiously supportive of the proposal, with most concerns revolving around the unknown budgetary impacts of COVID-19. Dean Genetti’s suggestion to relax the required TAship for doctoral students from two quarters to only one quarter should be seriously considered given the limited flexibility of TA allocations across the campus. With the uncertain fiscal implications of COVID-19 on the campus, the initiators will need to work with Deans Alferness and Wiltzius to address resources, specifically the transfer of FTE from departments that may now be unable to fill these lost faculty lines. We note, however, that the critical number of Faculty FTEs to bootstrap the program already exists across different departments. Our recommendation would be that depending upon the severity of the current budgetary situation, the pace of the FTE growth (which is already a quite modest 6 FTEs over 6 years) can be adjusted without jeopardizing the program due to delays incurred for better fiscal conditions in the state of California and the University of California. We also note that the establishment of this program does not require the campus to make any capital investments since the new BioEngineering building provides the necessary laboratory and office infrastructure for housing this program. Dean Genetti observes: “Indeed, it is refreshing to vet a proposal where access to sufficient space is not a central and intractable problem.”

In closing, we strongly endorse the proposal to establish a Graduate Degree Program and Academic Unit in Biological Engineering. The Academic Senate normally would require that budgetary concerns be fully addressed before approving a new program proposal. However, in these unprecedented times and with the uncertainties of the budget outlook, Graduate Council’s priority was reviewing the academic curriculum. This was found to be very strong, and GC acknowledges the years of work the campus has put into preparing for a Biological Engineering Program. While Graduate Council approves the establishment of the graduate program, it is to be understood that there are no assurances that the program can begin in the timeline stipulated in the proposal, or be allocated the resources that have been requested. These are conversations that need to be had with the administration before the proposal can move on to the next stages of review.

CC:
Debra Blake, Executive Director, Academic Senate
Carol Genetti, Dean, Graduate Division
Robert Hamm, Assistant Dean, Graduate Division
Rickie Smith, Director, Academic Services, Graduate Division
Toby Lazarowitz, Executive Assistant to the Executive Vice Chancellor
Steven Velasco, Director, Institutional Research, Planning & Assessment
Rod Alferness, Dean, College of Engineering
Michelle Veal, Executive Assistant to the Dean
Pierre Wiltzius, Executive Dean and Dean of Sciences, College of Letters & Science
Nancy Emerson, Executive Assistant to the Dean
To: Divyakant Agrawal, Chair  
Graduate Council  

From: Carol Genetti  
Anne and Michael Towbes Graduate Dean

Re: Proposed Doctoral Program in Biological Engineering

I write in strong support of the proposal to establish a doctoral program in Biological Engineering. Since 2011, the Center for BioEngineering – a central hub in the campus research infrastructure – has been bringing faculty together from a variety of disciplines to support groundbreaking research and, since 2014, running a Ph.D. Emphasis in BioEngineering. Discussions of gradually building out programs that would justify the eventual establishment of a new department in this area have been underway for years. The most visible sign of this is the impressive new BioEngineering Building. (Indeed, it is refreshing to vet a proposal where access to sufficient space is not a central and intractable problem.) The current document has long been expected and arises from years of work and consultation. It includes a proposal for a new doctoral degree, a corresponding master’s (not an independent degree program), and a new administrative Biological Engineering Program. Because of the interdisciplinary definition of the field, the Program is proposed to be inter-collegial and report to both the Dean of Mathematical, Life, and Physical Sciences (MLPS) and the Dean of the College of Engineering (CoE). The proposal states that “the degree itself, which is an engineering degree, will be administered solely by CoE” (p. 17). It is not clear to me what this means in terms of administrative processes and decision-making.

The program is being framed as “biological engineering,” the “application of engineering principles to the study of biology as a science, and the application of biological principles in the development of new technologies.” Although this is far from my own area of training, this appears to adequately differentiate the framing from similar programs at all of the other UC campuses.

The proposal provides convincing evidence of both student demand and workforce needs. According to data available in the UC Dashboard,¹ the number of total applications for bioengineering in the UC system in the 2014-15 academic year (the first year that such data was posted) was 720 with 120 admits. By the 2018-19 academic year (the latest year for data on the Dashboard), there were 1318 applications with 150 admits. Some of this increase may be due to students submitting multiple applications, but some of it indicates an abiding and increasing interest in the field.

The proposal projects a gradually expanding student body from its first projected cohort of 10-12 in 2021 to a steady state of 60-80. This fits the current campus plan of increasing graduate enrollments over time. This increase, like others, will put additional pressure on graduate housing, as well as on the campus administration to find permanent solutions for addressing housing shortages for graduate students.

The proposal contains a comprehensive and promising diversity plan that includes the laudable goal of having at least 50% of the student body be from demographic groups underrepresented in STEM (minorities, women, and first-generation college students). To achieve this goal, the proposal also notes that a great deal

¹ [https://www.universityofcalifornia.edu/infocenter/doctoral-program](https://www.universityofcalifornia.edu/infocenter/doctoral-program)
of focused attention will be placed on recruiting, admitting, and retaining those students. The Program has pledged itself to spending significant time and effort to establish an inclusive, welcoming climate for a diverse group of students. These efforts will be regularly evaluated by the Program and the campus for their effectiveness. The Graduate Division will be happy to partner in these efforts.

The proposed academic requirements and milestones are well-within our existing doctoral degree standards and practices. Students will be required to complete a unified core curriculum, select one out of three foci to emphasize (1. Biological Modeling and Signal Processing; 2. Synthetic Biology and Biomolecular Engineering, or 3. Cell, Tissue and Device Engineering), take courses in one other foci, as well as participate in lab rotations, elective seminars, and a pharmaceutical/industry course or industry internship. Normative time-to-advance will be in the spring of the third year and will require a written dissertation proposal, an oral defense of this proposal, and an oral examination by the pre-candidacy thesis committee. The pre-candidacy committee will not include the thesis adviser in order to encourage a more open exchange with the examinee. The normative time to finish the dissertation is at the end of year six. I would only suggest that when it comes time to write up the Biological Engineering Graduate Student Handbook, that the Program consider ways to provide multiple mentors to students. The pre-candidacy thesis committee may be one such opportunity.

The proposal includes an opportunity for a master’s degree for students who do not ultimately pursue a PhD. This degree has a thesis option (Master’s Plan I); presumably students who decide to leave will have some sort of paper that they will be able to develop into a thesis relatively quickly. The proposal also states that the master’s can be added by doctoral students who have advanced to candidacy. The Program needs to think about the master’s capstone in this case: would the dissertation proposal be submitted as a master’s thesis, or would this be Master’s Plan II with the qualifying exam also counting as the master’s exam (as is commonly done)? If the latter, then the proposal should include this as well.

Regarding resources, the proposal describes a cadre of twelve faculty from CoE and MLPS who are committed to moving half of their FTE into the proposed Program. This 6.0 FTE would then be supplemented by another eleven faculty who are willing to be affiliated with the Program at 0% time. Some of the support letters, however, offer something less than a ringing endorsement of this plan and suggest some caution. These positions are to be supplemented by the addition of six new faculty FTE over the coming six years, a hiring rate that might be achievable in a period of growth, but is unlikely to be achieved in one of budgetary contraction, as we now face. Departments with contributing faculty may also be justly cautious about their ability to backfill FTE following transfers out. Given the current situation, it is worth asking what it would mean to launch the program with fewer faculty resources, perhaps with smaller cohorts and greater reliance on cross-listed courses in other departments.

The proposal states the intention to fully fund all students for all six years of their matriculation, a goal which I enthusiastically endorse. At least three of those funding years will come from extramural sources and the rest will come through block grant (and presumably other central fellowships), development funds, TA positions, and training grants. The proposal convincingly argues that UCSB’s share of federal support from NIH “is under-developed” and that the existence of a bioengineering program will place UCSB in a position to draw on this funding. Moreover, there will be opportunities for training grants that may be able “to fund 2 to 3 new students per year through both first-year research rotations and second year didactic training.” This will be necessary if the Program is to recruit the size cohorts that they describe, especially as students doing rotations are typically not supported by research grants in their first year.
Regarding fellowship support, new doctoral programs receive a $50,000 annual block grant until they increase in size sufficiently to be awarded more by formula, a process that will take some years. These funds would probably be best directed towards paying Non-Resident Supplemental Tuition (NRST) for first-year students from out of state; the allocation could cover this cost for three students; the Program may want to especially focus on recruiting students from California, at least initially, to avoid this extra cost. In addition, the new Program would be given a Regents Fellowship in Biological Engineering (single year, minus NRST) to award to a student of its choice. It would also be eligible to nominate students for central fellowships. Based on patterns seen elsewhere on campus, in a typical year they may bring in about three students on central fellowships.

The proposal includes a request for nine quarters of TAship annually to be allocated to the Program from the Deans of CoE and MLPS (it is not clear whether this would include or supplement the three TA quarters that the campus currently allocates to CBE). I note that if all students are required to TA for two quarters, then this allocation will not be sufficient to realize that goal. While the students might find positions outside of the department, this cannot be guaranteed. Indeed, the Chair of MCDB expressed caution on exactly this point. Dean Wiltzius also sounds a note of caution on request for TAships, stating that any allocations will need to be justified by undergraduate enrollments. Given this, compounded with the likelihood of contractions of TA budgets over the next two to three years, it may be wiser for the Program to require only one quarter of TAing, even though it may strive to provide further opportunities. Since students in these fields are not typically supported on research grants in Year 1, but presumably work as TAs if they do not have full fellowships, then the Program may need to launch with smaller cohorts and grow gradually as resources become available.

Moving beyond funding, it is important to raise the question of impacts on other programs on campus. Of course, the establishment of such a program will bring the campus many benefits in terms of new research opportunities, collaborations, research grants, and enrichment of the intellectual vibrancy of the campus. This intangible contribution should not be underestimated. There will be new courses that could be of interest to graduate students from a wide range of disciplines, and eventually there will be a new undergraduate major in an exciting area of growth; these will be tangible benefits for students at all levels. More specifically, the new doctoral program will complement the Graduate Emphasis in Bioengineering, providing greater opportunities for its students. The administration of the Emphasis will be transferred out of CBE (a highly unusual arrangement) and into a proper Program.

The impact on the Program of Biomolecular Science and Engineering (BMSE) deserves special comment. I share Dean Wiltzius’ concerns that Biological Engineering might pull both faculty and students sufficiently away from BMSE to make sustaining that program a challenge. As noted, BMSE is at a critical juncture post-PRP and is at a moment of redefinition and rebranding.

The idea expressed in the proposal, the letter from the BMSE Director, and that from Dean Wiltzius, is that BMSE should receive attention and resources at this moment to ensure that it can remain robust, complementary, and synergistic with Biological Engineering. I strongly concur. In my view, the two programs should be thought of in tandem with regards to resources and with the express goal of creating an ecosystem that allows both to thrive. It will be especially important in the coming few years of budgetary contraction that the two programs are not in competition, as the result could be that neither of them realize their potential. Collaboration between the program directors and disciplinary deans towards the end of mutual enrichment will be important.
I hope that the Graduate Council finds this analysis to be helpful. I anticipate a further revision of the proposal and that I will be able to endorse it enthusiastically at that time.
April 7, 2020

TO:          Henning Bohn
             Divisional Chair, Academic Senate

FROM:         Dan Blumenthal, Chair
              College of Engineering, Faculty Executive Committee

RE:          Biological Engineering - Proposal to Establish a Graduate Degree Program and Academic Unit

The College of Engineering Faculty Executive Committee was asked to review the Biological Engineering Proposal to Establish a Graduate Degree Program and Academic Unit. The committee strongly supports the proposal.

8 yes, 0 no, 0 abstained (out of 10 eligible faculty members).
April 28, 2020

TO: Divyakant Agrawal
Chair, Graduate Council

FROM: James Roney
Chair, Letters and Science Faculty Executive Committee

RE: Proposal to create a biological engineering degree program

At its meeting on April 23, 2020, the Letters and Science Faculty Executive Committee (FEC) considered the proposal to establish a Biological Engineering PhD program. There was consensus that this should be a very successful program and that the necessary faculty, funding, and organizational structure were in place to facilitate its implementation. Nonetheless, various concerns regarding resource availability and possible adverse secondary impacts were raised during the course of our discussion.

The main concerns were related to the negative budgetary impacts of the current coronavirus emergency. The program proposal makes many references to future FTE positions, both to “backfill” faculty teaching and other efforts lost from home departments (and the BMSE program), and to expand the Bioengineering program itself. Given the bleak current budget projections and the latest estimates of FTE availability, this backfilling is no longer realistic in the short-term. This situation probably recommends a significant re-evaluation of the overall plan and its impacts on the relevant departments. The BMSE program, in particular, would appear to be in serious jeopardy of imploding if the current plan is implemented as proposed.

Possible courses of action include delaying full implementation of the program until there is better information about future budgets. Alternatively, the program might go forward without the formal commitment of FTE from specific faculty. Other inter-disciplinary programs on campus appear to operate without fixed allocations of FTE (e.g., Dean Wiltzius mentioned the Interdepartmental Graduate Program in Marine Science) and promulgation of the Biological Engineering program without a formal FTE commitment might allow for more flexible responses to future budget contingencies. At the very least, the home departments from which faculty for this program will be drawn might be consulted again in light of the fact that they are very unlikely to receive the FTE allocations that were anticipated before the onset of the coronavirus pandemic.

Related to some of the above resource considerations, our discussion also touched on the possible impact of this program on undergraduate education. Specifically, the commitment of faculty teaching to regular graduate courses might divert resources away from teaching undergraduate courses. The increasing percentage of undergraduate (and especially lower division) courses taught by temporary lecturers is a recurring issue in program reviews in L&S, and the Biological Engineering program could further exacerbate this problem in departments for which lower division teaching is already a serious concern (e.g., in MCDB). The FEC believes that this issue should be seriously considered as part of the overall review of the proposed program.

Notwithstanding the above concerns, we do re-iterate our general support for this program. Our concerns relate to the best way to implement the program (in terms of timing and FTE
allocation) given new budget complications, but there was general enthusiasm for establishing a Biological Engineering program at UCSB.

Thank you for the opportunity to comment.

cc: Pierre Wiltzius, Executive Dean of the College and Dean of Science
    Jeffrey Stopple, Associate Vice Chancellor and Dean, Undergraduate Education
To: Henning Bohn, Chair
   Academic Senate

From: Christopher Newfield, Chair
   Council on Planning & Budget

Re: Proposal to Establish a Biological Engineering Program

The Council on Planning and Budget (CPB) has reviewed the proposal to (1) create the Biological Engineering Program (hereafter, the Program) within the College of Engineering and MLPS in the College of Letters and Science and (2) establish a new graduate degree, a PhD in Biological Engineering, which the Program will administer. The strong interdisciplinary research climate at UCSB may position it to be a leader in biological engineering, a relatively new discipline combining "engineering for biology and engineering from biology". The Program and the new degree lie at the interface between engineering and the sciences. Together they will benefit from and complement the strong, existing research relationships between these communities at UCSB.

The Program derives from an existing unit at UCSB, the Center for Bioengineering (CBE), whose goal has been to consolidate groundbreaking research in Biological Engineering and Bioengineering. The Graduate Emphasis in Bioengineering created by the CBE, which has supported about 18 students per year since its inception, will continue under the Program. The focus of the new PhD will be distinct from the Graduate Emphasis in its deeper focus on graduate student training in biological engineering. The Program leverages recent strategic investments including the new bioengineering building and the hiring of new faculty members in anticipation of the proposed Program and new degree.

The primary objective of the Program is to educate graduate students in biological engineering by capitalizing on existing strengths at UCSB including engineering, biophysics, biochemistry, quantitative biology, and data science. Creation of the Program is motivated by three factors: (1) societal demand and demand by graduate students themselves for training at the intersection of biology and engineering; (2) the need to attract graduate students to advance the research agendas of the large and growing number of faculty working at the biology-engineering intersection; and (3) the new benefits that may accrue to existing departments from enhanced cross-disciplinary teaching and research activities, an enhanced intellectual climate, and strengthening the basis for increased research support.

The proposal advocates for an aggressive timeline of program development with the first cohort of students admitted during 2021 academic year and the first students enrolled in Fall 2022. Key to this timeline is the expertise and proactivity of existing faculty and the breadth of classes currently offered across many departments. Projected enrollment is 10-12 students in the first year, 12-15 in following years, and a steady state population of 60-80 PhD students. These
numbers correspond to 4 or fewer Program students per existing core and affiliated faculty identified in the proposal. Additional students will derive support from already-requested FTEs and new FTEs in affiliated departments. The recruiting of new students through the Program conforms to the goal of the Long-Range Development Plan to increase the number and percentage of graduate students at UCSB.

In the longer term, we agree that the Program is an important element in the future vision for biological engineering at UCSB. That vision includes the creation of a bioengineering department and an undergraduate degree program. TA’s to serve the future undergraduate program and related classes in other departments will come from the curriculum and training regime developed within the Program.

We expect that the Program will positively affect existing departments and programs at UCSB. Currently bioengineering efforts are dispersed across campus. Consequently, many qualified graduate applicants whom our bioengineering-oriented faculty would like to attract go elsewhere because there is no clear home for such students. The Program will also attract bio-oriented students to other programs in the STEM disciplines and thus it leverages existing strengths on the campus.

The Program will include a robust effort to increase diversity in UCSB’s engineering and science disciplines. This effort will be aided by studies suggesting that engineering disciplines with direct social and medical relevance appeal to students from under-represented (UR) groups. The goal is to have at least half of Program students come from groups now under-represented in the STEM disciplines. This effort will be enhanced by the large fraction of existing core and affiliated faculty who themselves are women, first-generation, or UR minorities. The Program’s Diversity Officer will work to ensure that best practices are followed to minimize biases during applicant evaluation and recruitment. The Diversity Officer will also work with Program faculty and staff to meet the challenges of retaining a diverse graduate population. Formal assessments about the effectiveness of the Program in meeting its diversity and inclusion goals will be conducted by an external evaluator named and funded in the proposal.

However, CPB has several concerns. The first involves the new resources that will be required to meet the challenges presented by start-up and ongoing administration of the Program.

Faculty FTE: as Dean Wiltzius noted, creation of the Program will result in FTE losses from MLPS departments that are already highly impacted by large undergraduate student numbers. If not replaced, these losses will increase the already high student/faculty ratios in MLPS and possibly harm junior faculty and their departments. Initially, 12 core faculty will transfer up to 50% of their FTE from existing departments to the Program. These transfers were anticipated and conform to promises made to newly-hired faculty about their partial FTE transfers. The Program expects contributions from an additional 11 faculty (0%) who have committed to teach a course and advise. To mitigate effects of reduced staffing due to these transfers, the College of Engineering intends to restore FTE to affected departments, so they regain their former strengths. This would require an additional 6 FTE. In addition, to support future viability of the Program, the Program expects 6 new faculty over 6 years. We agree that these new FTE would allow the Program to adapt to evolving teaching and research priorities within the Program itself and in participating departments. We also know that the faculty transfers are not lost to the campus, and that Program benefits will spillover to donor departments. Nonetheless, MLPS and COE would be contributing approximately 2 FTE per year for 6 years to the Program, and now in an uncertain post-Covid environment. For this rate of hiring to be maintained, the Program
would need to be at or near the top of both deans’ priority list over many years. Is it? On the other hand, if hiring is slowed, will this damage the Program’s effectiveness? We cannot answer these questions but hope Program faculty and deans weigh them carefully.

Teaching Assistants: The Program requests three 50% TA allocations which will support its teaching mission and allow its graduate students to fulfill their 2-quarter TA obligation. Other graduate student support will come from external sources such as the NIH T32 training grants. Faculty associated with CBE have already demonstrated their ability to obtain high levels of support from NIH grants. This level of support seems quite feasible to us.

Staffing: Support for Program leadership including the Director, the Associate Director, and the Assistant Director will come from the existing budget of the CBE as will some staff positions such as the Graduate Advisor, and the Assistant Business Officer. A new staff position, an Administrative Officer, will also be hired. As the Staff Expansion Program has been suspended, and is unlikely to be re-started until the budgetary effects of Covid-19 are past, the Program’s core faculty might consider how hiring delays will affect them.

Space: We are very pleased to understand that the new Bioengineering building will satisfy space requirements of the Program. To reduce use of research equipment by graduate students in their courses, a one-time request of $350K will fund a new microscope; the Dean of the College of Engineering has committed to pay half of this cost. Costs to run Program laboratory courses and provide necessary supplies is estimated to be $15k per year. These appear to be manageable costs.

Relations with other programs: Dean Wiltzus also noted that development of the Program will require coordination with the valuable Program in Biomolecular Science and Engineering (BMSE), a program which is currently re-envisioning its future. BMSE Director Rothman supports creation of the Program but emphasizes the need to replace the FTE that will be transferred to the Program. He warns that loss of these FTE without replacement would cause “devastating negative impact” on the revitalization and rebranding efforts now underway in BMSE. CPB was also concerned about competition for resources in the forthcoming budgetary climate. Will COE and MLP have to choose between these two programs? This is a real possibility that we ask the administration to consider.

In summary, CPB strongly endorses the proposal’s vision and plan for the new Program and associated PhD in Biological Engineering. We also ask that the deans, core Program faculty, and other affected parties weigh the budgetary and planning implications together in the new environment.

cc: Debra Blake, Academic Senate Executive Director
May 11, 2020

To: Divyakant Agrawal, Chair
   Graduate Council

From: Eric Prieto, Chair
   Undergraduate Council

RE: Proposal for a Graduate Degree Program and Academic Unit in Bioengineering

The Undergraduate Council has considered the proposal to establish a doctoral program and an academic unit in Bioengineering. The Council was generally supportive, and would be pleased to see an increase in enrollment at the graduate level and also potential teaching assistants in the life sciences and engineering. However, before being able to offer its endorsement, UgC would like to see a commitment to refilling lost FTE in peer departments if and when faculty transfers take place.
April 10, 2020

To: Henning Bohn, Divisional Chair
    Academic Senate

From: Paul Berkowitz, Chair
      Committee on Library, Information, and Instructional Resources

Re: Proposal to Establish a Biological Engineering Graduate Degree Program and Academic Unit

At its meeting of April 3, 2020, the Committee on Library, Information, and Instructional Resources (CLIIR) reviewed the proposal to establish a graduate degree program and academic unit for Biological Engineering.

The committee focused strictly on needs and uses related to library and instructional resources and had no concerns as the proposed program does not require any additional call or demand on these campus resources.

Members noted that the program seems strong and needed by campus. The committee was unanimous in support of the proposed program and academic unit.

CC: Debra Blake, Executive Director, Academic Senate
Re: Proposal to Establish a Graduate Degree Program and Academic Unit in Biological Engineering

At its meeting of April 17, 2020, the Committee on Research Policy and Procedures (CRPP) reviewed the Proposal to Establish a Graduate Degree Program and Academic Unit in Biological Engineering.

The members are supportive of the program overall. They feel that the proposed program and academic unit make sense for the future of the university.

The members are concerned over the extent to which this program will compete with the existing Biomolecular Science and Engineering program.

The members also would like to ensure that the program has a strong start. Given the significant effort to start a program, and the current climate and budgetary adjustments related to the COVID-19 pandemic, they expressed reservations about the 2021 start date. Members questioned why none of the core faculty had appointments greater than 50% and whether that might hinder the success of the program.

Finally, members would like to see an explanation of the Center for BioEngineering (CBE)’s role in the program and academic unit. Will they remain separate entities and if so, why?

CC: Debra Blake, Executive Director, Academic Senate
PROPOSAL TO CREATE:

1. A NEW ACADEMIC UNIT JOINTLY IN THE COLLEGE OF ENGINEERING AND MATH, LIFE, AND PHYSICAL SCIENCES IN THE COLLEGE OF LETTERS AND SCIENCE: The Biological Engineering Program

2. A NEW GRADUATE DEGREE: A PhD in Biological Engineering

Date of Preparation: February 26, 2020

This proposal was prepared by the Bioengineering Curriculum committee of the Center for Bioengineering and is submitted by CBE Director Beth Pruitt on behalf of the proposed Core Faculty.

Beth Pruitt
Professor, Mechanical Engineering, Molecular, Cellular and Developmental Biology; Director, CBE

Kevin Plaxco
Professor, Chemistry and Biochemistry; Associate Director, CBE

Otger Campus
Associate Professor, Mechanical Engineering

Dennis Clegg
Professor, Molecular, Cellular and Developmental Biology

Siddarth Dey
Assistant Professor, Chemical Engineering

Adele Doyle
Assistant Professor, Mechanical Engineering

Michelle O’Malley
Associate Professor, Chemical Engineering

Arnab Mukherjee
Assistant Professor, Chemical Engineering

Spencer Smith,
Associate Professor, Electrical and Computer Engineering

Sebastian Streichan
Assistant Professor, Physics

Ryan Stowers
Assistant Professor, Mechanical Engineering

Max Wilson
Assistant Professor, Molecular, Cellular and Developmental Biology
EXECUTIVE SUMMARY

The UCSB faculty members whose research and teaching lie at the intersection of engineering and the life sciences are seeking approval to create a PhD degree in Biological Engineering and an administering unit entitled the Biological Engineering Program. The proposed PhD, which leverages our campus’s notably strong and collaborative relationship between engineering and the sciences, will be unique among UC offerings in the area of bioengineering in focusing on Biological Engineering. That is, in uniting both the application of biological principles, materials and systems to create tangible, economically viable solutions to technological challenges, and in parallel, the application of the tools and concepts of engineering to advance our understanding of biology as a science.

By helping to fulfill growing demand for researchers and educators trained at the interface of biology and engineering, the proposed Program meets many important campus, state and societal needs. At the campus level, the proposed Program will fill an increasingly critical void in our pedagogy by providing training in the newest, and arguably fastest growing engineering discipline; UCSB is the only UC campus lacking a graduate degree in any of the bioengineering sub-disciplines. (Note: the only degree offered by our existing Biomolecular Science and Engineering Program is Biochemistry and Molecular Biology, not bioengineering.) It will also bring to our campus a strong and diverse cohort of graduate students who do not currently apply to UCSB, which in turn will support the research and training efforts of the rapidly increasing number of faculty members working in this area. Finally, the proposed Program will help the University of California meet important state and societal needs. The Bureau of Labor Statistics, for example, predicts 10% growth in California bioengineering jobs over the decade from 2016. Consistent with this, student demand is outpacing the UC system’s ability to provide bioengineering training; our sister campuses already turn away large numbers of qualified graduate applicants.

Existing campus conditions and strengths favorably dispose the proposed Biological Engineering Program for success and the ability to rapidly achieve a highly competitive ranking. Despite not yet offering any graduate degree focused on this or any other Bioengineering sub-discipline, our campus research efforts in this field already receive widespread recognition and significant extramural funding. The Program will also leverage the strategic investments that existing campus departments have made in recent years in anticipation of the formation of the proposed Program, which include the hiring of the majority of the faculty members who authored this proposal. Indeed, the hiring of these individuals was predicated on the expectation that the campus at large would invest in this area so as to reinforce these synergistic relationships. Without the emergence of a formal Program in Biological Engineering, these faculty members and the departments that house them will have difficulty becoming more competitive and attracting the desired expansion in trainees and funding in this area. Moving forward, we anticipate that the Program will continue to make joint appointments in collaboration with existing departments and Programs in both the College of Engineering (CoE) and Math, Life, and Physical Sciences (MLPS), further cementing our campus’s collaborative, interdisciplinary tradition.

Housed in the campus’s new Bioengineering Building, the proposed Program will serve three roles. First, it will administer the PhD in Biological Engineering proposed here. Second, it will assume administration of our existing Graduate Emphasis in Bioengineering, an effort already providing, specialized bioengineering training to students enrolled in 13 affiliated MLPS and CoE PhD programs. Finally, it will serve as cornerstone to the campus’s long-range plan of founding a Department of Biological Engineering, which eventually will also include an undergraduate degree in bioengineering.

In support of these goals 12 current UCSB faculty members have committed to serve as “Core Faculty” and will transfer partial FTE into the Program at its initiation. Another 11 “Affiliated Faculty,” who will receive 0% appointments, have committed to providing additional research opportunities and coursework.
Table of Contents

Executive Summary..........................................................................................................................2

Section I: Introduction.....................................................................................................................4

Section II: Program..........................................................................................................................18

Section III: Projected Need.............................................................................................................23

Section IV: Faculty..........................................................................................................................27

Section V: Courses..........................................................................................................................29

Section VI: Resources......................................................................................................................36

Section VII: Graduate student support..........................................................................................40

Section VIII: Governance...............................................................................................................42

Section IX: Changes in senate regulations....................................................................................43

Appendix A: Administration Letters of Support.........................................................................44

Appendix B: Departmental Letters of Support..............................................................................54

Appendix C: Bioengineering Institute of California Letters of Support......................................71

Appendix D: Proposed bylaws for the Biological Engineering Program.....................................75

Appendix E: Letters of Commitment from the Core and Associated Faculty.........................79

Appendix F: Existing and Proposed Core and Focus Area Courses........................................104

Appendix G: Degree Sheet............................................................................................................174

Appendix H: Budget.......................................................................................................................181

Appendix I: Professional Qualifications of the Core Faculty....................................................187
SECTION I. INTRODUCTION

We herein propose the establishment at UCSB of a graduate degree (and an administering Program) leading to a Doctor of Philosophy (PhD) in Biological Engineering. As the 21st century progresses, the science of biology is proving an increasingly deep and inspiring source of new concepts, mechanisms and materials for application across each of the traditional engineering disciplines. In synergistic parallel, the application of novel technologies and concepts emerging from these same engineering disciplines is rapidly advancing the science of biology. Taken together these two endeavors – engineering from biology and engineering for biology – comprise the discipline of biological engineering, a relatively new field that combines discoveries in the life sciences with the fundamental principles of engineering in furtherance of both. We propose the creation of both a new graduate degree in this field and an administering Program, which will be staffed by faculty members recruited from multiple departments across the college of engineering (CoE) and Math, Life and Physical Sciences (MLPS). The proposed Program and degree, which in terms of both pedagogy and research sits squarely at the interface of Engineering and the Sciences, will benefit critically from the strong relationships that already exist between these communities at UCSB, a unique strength of our campus. Participating departments will, in turn, benefit from the additional cross-disciplinary teaching and research activities that the Program will provide. In addition to strengthening the campus’s intellectual environment, these activities will also provide new educational opportunities for our students, attract a large and diverse cohort of students who are currently not applying to our campus, and create significant new opportunities for research and extramural funding. The proposed Program will also ultimately serve as cornerstone to the campus’s long-range plan of founding a Department of Biological Engineering, which eventually will also include an undergraduate degree (Figure 1).

Figure 1. Roadmap for the creation of the graduate Program in Biological Engineering proposed here (in blue) and, ultimately, a Department and an undergraduate degree (in yellow). Although creation of the latter two is well beyond the scope of this proposal, and thus is not described here in any detail, our anticipation is that, given the multi-year approval cycles for the Graduate Program and the Department and the time required to implement our proposed FTE plan, we will be ready to launch an undergraduate degree approximately 5 years after the initiation of the graduate Program.
The proposal presented here grows out of an existing campus unit, the Center for Bioengineering (CBE). Founded in 2011, CBE was created as the campus “home” of Bioengineering—a field that encompasses both Biological Engineering and Biomedical Engineering—with its goal being to consolidate UCSB’s position and support groundbreaking research in both. To support the research and educational goals of UCSB’s bioengineering community, CBE created a Graduate Emphasis in Bioengineering in 2014. The Emphasis, which we propose will continue under Program administration, provides additional training in bioengineering topics to students pursuing graduate degrees in one of 13 existing programs. Given the number of students training in more established disciplines on our campus who seek to augment their PhD with knowledge in bioengineering and biotechnology, the Emphasis continues to be an important piece of UCSB’s graduate training landscape. Specifically, the Emphasis has served an average of 18 students/year from the affiliated programs, providing them valuable, biology-oriented augmentation to the more traditional engineering and physical science training they receive in their home programs. This said, the Emphasis is not designed to meet the growing demand for more deeply focused graduate training in biological engineering, thus motivating the PhD program proposed here.

The proposed program heavily leverages significant, recent campus investments in the area of bioengineering. This investment includes the 2017 completion of a state-of-the-art Bioengineering building that is centrally located on campus and that houses both the CBE and the Institute for Collaborative Biotechnologies (Figure 2). In parallel, existing campus departments in both CoE and MLPS have, in recent years, made significant, strategic investments in anticipation of the formation of the proposed Program, including the hiring of the majority of the faculty members who authored this

-In this proposal we use the phrase “bioengineering” to denote the broader discipline that includes both “biological engineering” (engineering from biology, and the application of engineering principles to the study of biology) and “biomedical engineering” (engineering in the service of translating technology to meet immediate medical needs).
proposal. The proposed Program will build on these timely investments to deliver a world-class graduate education.

Finally, the research and training opportunities provided by the proposed Program will significantly augment our campus’s extramural funding. For example, UCSB currently receives less funding from the NIH than almost any other UC campus, including those that, like our campus, lack a medical school (Figure 3). In this regard, it is notable that, despite their still relatively small numbers, the bioengineering-oriented faculty members at UCSB serve as principle investigators on approximately 25% of the current NIH grants awarded to our campus. Taken together, these arguments suggest that the establishment of the proposed degree Program, the investment in additional faculty in this area, and the concomitant marshaling of faculty members around common themes in biological engineering, would enhance the campus’s competitiveness, thereby helping to secure additional support from this and other sources of research funding relatively untapped on our campus.

Figure 3. (Left) Total NIH funding to all UC campuses in FY 19. (Right) A comparison of FY 19 NIH funding levels at UC campuses that, like UCSB, do not have a medical school.

1. Aims and objectives of the program

Application of engineering principles – and the quantitative, predictive modeling upon which engineering relies– to the science of biology is revolutionizing our understanding of both health and disease. In parallel, our improved understanding of the life sciences is providing powerful new innovations in engineering. These advances are ushering in a new era of biology-derived and biology-inspired technologies responsive to a wide range of challenges in manufacturing, agriculture, the environment and, of course, medicine. Taken together these two endeavors –engineering for biology and engineering from biology– comprise the field of biological engineering, an intellectual arena in which, due to its unusually close relationship between engineering and the sciences, our campus is poised to thrive. Indeed, the foundation upon which we propose to build Biological Engineering at UCSB is so strong that we expect the proposed Program will rapidly be ranked among the top programs in this field.

The primary objective of the proposed degree is to provide students with formal training in biological engineering that unites UCSB strengths in engineering, biophysics, biochemistry, quantitative biology, and data sciences into a strong, coherent, forward-looking curriculum. Our motivation for this stems from a confluence of factors. First, as noted below there is rapidly growing societal demand for students trained at this interface and a concomitant growth in student demand for graduate training in biological engineering, demand that UCSB is currently failing to meet. Second, the creation of the proposed
graduate degree program will help the large—and increasing—number of faculty members on our campus who work at the intersection of biology and engineering to attract the students necessary to pursue their many and varied research agendas. Finally, we are also motivated by the benefit that the campus’s existing science and engineering departments will accrue from the cross-disciplinary teaching and research activities, the enhanced intellectual environment, and the stronger basis for extramural funding opportunities that the proposed Program will provide.

2. Historical development of the field and historical development of departmental strength in the field

Biological engineering, and the associated (and broader) field of bioengineering, are among the newest of the engineering sub-disciplines, with the word “bioengineering” only having been coined in 1954. Its relative youth notwithstanding, the field is now an established pillar in most of the country’s top engineering colleges. In 2019, for example, U.S. News & World Reports ranked 131 graduate programs in “biomedical engineering,” encompassing biomedical engineering, biological engineering, and bioengineering. The first of these, those at Johns Hopkins University, University of Pennsylvania, and University of Rochester, were founded in 1961. Five years later our sister campus at San Diego created the University of California’s first graduate program in bioengineering, which was founded in the Department of Applied Mechanics and Engineering Science as a joint venture with the School of Medicine (this became a department in 1994). Today, every UC campus except UCSB offers one or more degrees in bioengineering.

Bioengineering as a discipline is supported by a collaborative and cohesive educational community, which has guided and fostered the development of bioengineering training nationwide. The discipline’s key professional society, the Biomedical Engineering Society, held its first annual meeting in 1968. Administratively supported by this organization, the bioengineering Council of Chairs is a body comprised of the heads of bioengineering departments and programs. Council of Chairs meets twice yearly to promote sharing of best practices in curriculum, professional development, and recruitment/retention activities supporting student training and workforce development. As UCSB has been building toward bioengineering programs and a department, CBE Director Pruitt became a member of Council of Chairs in 2018 in order to participate in the community, promote our activities and benchmark them against those of other, longer established programs. For example, Council of Chairs organized the 3rd Education Summit in 2019 to bring together faculty members from Council of Chairs members to discuss how to improve training programs and workforce development. Three faculty members from UCSB (Pruitt, Plaxco, Dey) participated in this workshop to benchmark best practices for graduate and undergraduate degree programs. Pruitt also helped develop and run a workshop on problem and project-based learning at this Summit.

Despite its being the only UC campus without a department or a graduate program in the field, UCSB has nevertheless already established a nationally recognized research presence in the area that is driven by our unimpeachable strength in engineering and our deeply ingrained tradition of cross-college interdisciplinarity. In the past three years alone, for example, UCSB has hired numerous new faculty members across engineering and sciences who are focused on Biological Engineering (e.g., Beyeler, Dey, Dogic, Doyle, Dressaire, Louis, Marchetti, Mukherjee, Pitenis, Pruitt, Smith, Stowers, Streichan, Wilson, Takatori, Yeung). We would like to note that all of these faculty were recruited to UCSB under the promise that a Biological Engineering Program was on the horizon, and several (e.g., Dey, Doyle, Pruitt, Stowers) were hired under the explicit promise that they could transfer significant FTE into the Program when it comes on line.

3. Timetable for development of the Program

We propose to open admission for our first graduate cohort during the 2021 academic year, leading to our
first enrolled students in Fall of 2022. Notably, UC Santa Barbara is scheduled to host and organize the UC-wide Bioengineering Symposium in Spring 2021, offering an excellent venue at which to advertise the imminent launch of the new Program. While this may appear an aggressive implementation timescale, it can be achieved given the expertise and enthusiasm of the campus’s existing faculty members, the breadth of existing courses we propose to leverage, and the gracious willingness of existing departments to open their courses to these students. Numerous opportunities for graduate research in biological engineering already exist and are currently spread across many departments. The proposed Program would connect and train students with interests matched to these opportunities and labs. The projected enrollment is targeted at 10-12 students in the first year, with 12-15 new students each subsequent year. Total enrollment in steady state (five to seven years) is anticipated at 60-80 PhD students. Even considering only the initial roster of Core and Affiliated Faculty (i.e., ignoring for a moment the faculty FTEs that we have requested and any additional hiring in affiliated departments), this corresponds to fewer than 3 to 4 Program students per Program faculty member, a number that is consistent with typical steady state sizes of 6-10 students for these groups (which would also include students from the faculty member’s home program). Given the significant research funding that the campus’s current bioengineering-focused faculty enjoy and the tremendous student (and societal) interest in bioengineering training, this high level of enrollment is easily justified. It is also consistent with the goal of significantly increasing the number and percentage of graduate students at UCSB, as outlined in the campus’s Long-Range Development Plan.

The proposed Program is a first and critical element of the campus’s longer-range timeline and vision for biological engineering (Figure 1), which will ultimately include the creation of both a department and an associated undergraduate degree. This long-range plan is consistent with the campus’s (and CoE’s) goal of increasing undergraduate enrollment in Engineering. A critical element in this vision, the proposed Program will not only foster the development of new biological engineering curriculum, but also train the cadre of graduate students necessary to serve as TAs in related undergraduate courses in both the College of Engineering and the College of Letters and Sciences. Of note, the proposed effort parallels and synergizes with broader campus trends. For example, to meet growing demand from undergraduates for biological engineering training, the Department of Mechanical Engineering is currently developing a bioengineering track in its undergraduate degree program. Based on recent enrollment data in bioengineering themed courses offered in Mechanical Engineering, Physics, and Chemical Engineering (Table 1), we anticipate that undergraduate demand for bioengineering courses will likely exceed that from graduate students. With concomitant TA support our Program curriculum would be well positioned to support increasing demand on campus for upper division electives in undergraduate programs.

<p>| Table 1. Recent enrollment in existing bio-engineering oriented courses |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|</p>
<table>
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<tr>
<th>Quarter</th>
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4. Relationship to and effect on campus and the Campus Academic Plan

The proposed Program, which is fully supported by the Deans of both CoE and MLPS and other key campus administrators (see, for example, the letters of support in Appendix A), is fully consistent with the 2007-2025 UC Santa Barbara Strategic Academic Plan, which identifies the emerging area of “biotechnology” as a major campus priority. This was motivated by both faculty research interests and by significant interest from both prospective and current students in graduate degree programs focused on the applications of biology to human problems.

The creation of the proposed Program will significantly and positively impact many of our campus’s existing departments and programs by solving a long-standing structural problem: although all CoE and many MLPS departments include an increasing number of bioengineering-oriented faculty members, no single graduate program on our campus serves as an obvious home to bioengineering-oriented prospective graduate students. Because of the dispersed nature of our campus’s bioengineering efforts, we are failing to attract the type of graduate student applicants our bioengineering-oriented faculty members would like to train. The proposal you are currently reading is a direct response to this situation, in which the rapidly growing faculty demand for bioengineering-oriented students (and thus, in turn, the retention of these faculty members) is hindered by the lack of any formal bioengineering program that would draw students with matched interests.

In addition to providing a home for students interested specifically in biological engineering, the proposed Program will also augment the efforts of existing departments to themselves attract bio-oriented graduate students who are interested in pursuing training in one of the more established STEM disciplines. Specifically, the proposed Program will leverage and organize the strengths that exist across campus, promote a higher profile in the field, and provide a more effective way of recruiting these students. For example, the creation of the Bioengineering Graduate Emphasis and its associated courses enabled the Mechanical Engineering Department to create its now increasingly popular graduate track in Bioengineering and Systems Biology. Likewise, in recent years the Departments of Mechanical Engineering, Chemical Engineering, Electrical and Computer Engineering, and Materials science have employed the promise of further, formal growth in bioengineering to help recruit many strong, bio-oriented junior and senior faculty members to our campus. The proposed Program also aligns well with ongoing efforts to build data science programs on our campus. Specifically, data science and machine learning are playing increasingly important roles in biological engineering research and pedagogy, and thus the proposed Program will both benefit from and contribute to these efforts. The creation of the graduate degree proposed here will likely accelerate all of these trends. For example, the courses that will be created in support of the proposed Program will augment ongoing efforts to create bio-oriented graduate tracks in Chemical Engineering and Physics (see departmental letters of support; Appendix B), and will likely seed still more efforts in other departments on our campus.

Creation of the proposed Program will also significant impact the three existing interdepartmental graduate Programs on our campus: The Biomolecular Science and Engineering (BMSE) Program, the Graduate Emphasis in Bioengineering, and the Dynamical Neuroscience (DYNS) Program.

The Biomolecular Science and Engineering Program (BMSE). The BMSE Program may be the most significantly impacted of our campus’s existing departments and graduate programs (see letter from Director Rothman in Appendix B). When considered carefully, however, we believe that the negative impact the proposed Program may have on BMSE will be small, and are outweighed by the many positive impacts the proposed Program will have on both BMSE and our campus’s broader research and academic efforts. Specifically:

a) The proposed Biological Engineering Program addresses a significant campus need that the BMSE Program has historically proven unable to fulfill. Specifically, in contrast to the large
number of UCSB faculty members who seek to recruit biological engineering students (23 faculty members, for example, have already agreed to participate in the proposed Biological Engineering Program as either Core or Affiliated faculty), the number of bioengineering students who enroll in BMSE is small (averaging fewer than 6 per year), and the majority of these are neither interested in nor have prior training in bioengineering. This paucity of engineering-oriented student recruits occurs in large part because the only degree (and training) offered by BMSE is in Biochemistry and Molecular Biology. That is, although the Program rebranded itself (from the “Biochemistry and Molecular Biology Program”) as Biomolecular Science and Engineering almost 20 years ago, its curriculum and intellectual “centers-of-mass” remain firmly in the sciences, which limits interest by bioengineering-oriented students. In short, without a dedicated, biology-focused engineering degree and its associated, engineering-oriented curriculum, our campus will continue to fail in its efforts to attract this important cohort of students.

b) The impact of faculty FTE transfers on the BMSE Program will be relatively small. The BMSE faculty is comprised of 23 members with non-zero appointments and an additional 10 with 0% appointments. Given this size, the proposal by four faculty members to move FTE (up to 1.33 counting Clegg, Plaxco, Pruitt, Streichan) to the proposed Program does not represent an insurmountable burden. Moreover, these faculty members intend to retain at least 0% appointments in the Program, provide continuing opportunities for BMSE graduate student research, and teach courses in Biological Engineering also of benefit to the BMSE curriculum.

c) There are significant opportunities to ameliorate any negative impact BMSE may suffer and potential for significant benefit to BMSE from the emergence of the proposed Program. For example, the proposed FTE needed to grow Biological Engineering on campus is expected in part to be through joint hires with BMSE and other programs with common interests, e.g., systems biology, biological modeling, and other quantitative aspects of engineering and from biology. Such additional hires will easily “back fill” teaching and research capacity to provide a net growth in training opportunities for students both in the new Program and in BMSE.

d) The emergence of the proposed Program is already providing the opportunity to re-vitalize the BMSE program, as described by BMSE Director Joel Rothman in the letter he provided (Appendix B). Specifically, BMSE’s 2016 PRP report noted that emerging plans to build a new and separate program in the area of bioengineering before explicitly and forcefully arguing that BMSE should use the opportunity to re-define and re-focus on its core mission. BMSE’s formal response to the PRP noted their intention to reform and rebrand around themes of quantitative biology. To this end, the BMSE Director has recently begun discussions regarding a re-envisioning of the Program, provisionally to be known as the Program in Quantitative Biomolecular and Biosystems Science (iQB2). Several of the new courses proposed in the Biological Engineering curriculum will likely be of interest to students in the re-branded Program, and will thus augment these revitalization efforts.

**Graduate Emphasis in Bioengineering.** As described above, the Interdisciplinary Graduate Emphasis in Bioengineering, which is currently administered by CBE, provides students in 13 of the campus’s PhD programs with training in bioengineering topics. To date the Emphasis has served an average of 18 students/year from the affiliated programs, providing them biology-oriented augmentation to the more traditional engineering and physical science training they receive in their home programs. In parallel, the CBE is currently in discussions with several partnering CoE and MLPS undergraduate programs that wish to use the Emphasis’s course offerings as upper division electives in new bioengineering-oriented undergraduate tracks. We thus believe it important that the Emphasis continue to serve the many campus stakeholders whose needs would be poorly met by the stand-alone PhD Program proposed here and it is our intention is for the Emphasis to remain an active and vibrant part of our campus’s educational offerings. This said, it is more appropriate for an educational effort such as this to be administered by a
Program rather than, as is currently the situation, a Center (CBE). Indeed, the Emphasis was originally endorsed by the various stakeholders on our campus with the understanding that it would ultimately be “housed” in a formal Program. We thus propose that administration of the Emphasis will transfer to the Biological Engineering Program. Other than this change in administration, however, our expectation is that, pending continued student and campus demand, the Emphasis will continue its service to the campus unchanged.

**Dynamical Neurosciences (DYNS).** A third Program with which there is overlap is the recently formed DYNS graduate program, which draws on existing courses in the departments of Psychological and Brain Sciences, Physics, Molecular, Cellular and Developmental Biology, Computer Science, and Electrical and Computer Engineering. The DYNS Program is built around an interdisciplinary curriculum comprised of a set of 5 core courses offered by these five departments and focused on measuring and modeling how the brain and nervous system work. The intersections of DYNS and the proposed Program are thus likewise viewed by the leadership of both Programs as synergistic rather than competitive (see attached letter of support), as both Programs will leverage the courses of the other as electives. This is particularly true of the Program’s Interdisciplinary PhD Emphasis; the Biological Engineering curriculum will significantly augment the courses available on campus to support this emphasis.

We note, too, that we do not believe the proposed Program will find itself in significant competition for students with any of the campus’s existing departments or Programs. That is, although existing CoE departments and the Biomedical Science and Engineering (BMSE) program interview a number of strong, bioengineering-oriented graduate applicants every year, relatively few accept our offers of enrollment due to a lack of bioengineering focus in the existing curricula, and the limited focus on bioengineering in any single existing department. Moreover, those few bio-oriented engineering students who have, historically, enrolled in the campus’s existing graduate programs tend to be those seeking training in the more well-established sub-disciplines (e.g., in Chemical or Mechanical Engineering, or, in the case of BMSE, in the basic biological sciences) rather than “deep-dive” training specifically in biological engineering; we thus do not expect many of these students to be diverted by the creation of a the proposed Biological Engineering Program.

Although being proposed in support of a new graduate Program, the biological engineering curriculum will also positively impact undergraduate education on our campus. For example, CBE is already working with Mechanical Engineering on a proposal to create an undergraduate bioengineering and systems biology track within that department that leverages accessibility to the Bioengineering Emphasis curriculum by upper division undergraduate majors; our intention is that that this and similar efforts with other CoE departments will continue with the Proposed program. The proposed Program will also lay the groundwork for our longer-term plans to, as noted above, create an undergraduate degree program in this discipline.

Although well beyond the remit of this proposal, which is proposing solely the creation of a graduate degree, in broad strokes our anticipation is that we will be in a position to create the latter approximately 2 years after establishment of the Department of Biological Engineering.

The proposed Program will also help meet pressing campus needs associated with the rapidly growing enrollment in bio-oriented undergraduate courses and degrees in our existing departments. For example, any graduate student admitted to the Program will be a well prepared, highly desirable candidate to fill TA positions in many of the campus departments that have been struggling to find sufficient numbers of qualified, bio-trained candidates, including Molecular, Cellular and Developmental Biology, Chemistry and Biochemistry, and a number of engineering disciplines. In parallel, by opening several elective courses in the proposed Program to upper division undergraduates, the Program will immediately help relieve the undergraduate enrollment pressures in impacted undergraduate degree programs in MLPS, including biology, biochemistry, and physics.
Finally, the proposed Program will significantly impact the Center for Bioengineering, which was founded some years ago as a means of fostering bioengineering education and research on our campus, and which served as the founding home of the graduate Emphasis. Our anticipation is that the Program will assume the academic responsibilities of CBE and leverage resources currently allocated to CBE. During the transition to Department status, CBE will continue to exist as a marketing portal to connect prospective trainees, faculty or donors with related programs serving biological engineering and sciences across campus.

5. Contributions to diversity

Interdisciplinary engineering and technology fields, characterized by clear social and medical impact, have historically proven appealing to students from under-represented (UR) backgrounds. The creation of a Biological Engineering Program will thus provide a powerful opportunity to increase diversity in UCSB’s engineering disciplines. In response, our goal is to create a Program in which at least 50% of our students are from demographic groups underrepresented in STEM (minorities, women, and first-generation college students), a level of UR contribution that matches the most diverse tier-one Bioengineering graduate programs in the nation (based on comparator data available through NSF career and graduate surveys). We believe this is achievable given:

- the notably diverse applicant pool that the field of bioengineering traditionally attracts;
- the notable diversity of our Core and Affiliated faculty, 40% of whom are women, first generation, or UR minorities;
- our campus’s broad and demonstrably successful commitment to diversity and equity (e.g., in 2015 UCSB became the first member of the Association of American Universities to be designated a Hispanic-Serving Institution);
- the diligence, dedication and, best-practices training of the Program faculty;
- and the continuous re-evaluation and re-optimization of our efforts informed by systematic, rigorous, and ongoing self- and external-evaluation of their effectiveness.

Our effort to build an inclusive, diverse, and equitable Program begins with student recruitment, an effort that will be aided by the fact that the undergraduate student base in bioengineering is by far the most diverse among the engineering sub-disciplines: both undergraduate enrollment and the fraction of degrees-granted in bioengineering and biomedical engineering are more than 40% female, 7% Hispanic, and 3.5% African American. To capitalize on this diverse potential applicant pool the CBE already promotes the 13 PhD graduate programs that it serves by participating in recruiting activities at the national meetings of the biophysical society and biomedical engineering society, and several CBE faculty are Co-PIs in UCSB’s NSF-funded Bridges to the Doctorate program. The Program will build on this foundation by, for example, partnering with graduate division to send both faculty members and students to the Annual Biomedical Research Conference for Minority Students and to the more broadly focused, but still STEM-based, annual meeting of the Society for Advancement of Chicanos/Hispanics and Native Americans in Science, which will provide opportunities to promote our campus and the Program to a large and diverse talent pool.

Of course, recruiting a diverse applicant pool is only the beginning; biases still exist in applicant evaluation and admissions. To help minimize the impact of these potential pitfalls we will appoint a Diversity Officer responsible for ensuring best-practices are maintained during every step of recruitment,

‡Shapiro, “Correcting the bias against interdisciplinary research.” eLife, 2014, 3e-2576
§DataUSA: Biomedical and Bioengineering Degree Programs; https://datausa.io/profile/cip/biomedical-engineering
admissions, and training. With regard to admissions specifically, these practices will include, but are not limited to:

- Including a statement of contributions to diversity, equity, and inclusion as an element in the application package, and using these as an equal measure in evaluating applications.
- Creating a prominent diversity page on the Program website and including a compelling diversity/equity/inclusion element in the Program mission statement.
- Ensure the admissions committee receives annual training on implicit bias and best practices for promoting diversity in graduate admissions.
- Employing rubric-based evaluation to achieve systematized, holistic review; the use of such rubrics increases objectivity and improves transparency and accountability while also reducing admissions committee time and effort.

Fostering an environment that achieves high levels of UR student retention is likewise a critical element of creating a diverse, equitable, and inclusive Program. To this end, the Diversity Officer will lead Program faculty professional development regarding best practices in the creation of a welcoming climate, the avoidance of micro-aggressions, the importance of bystander interventions, and the creation of an inclusive environment. In short, this faculty member will lead our shared efforts to inculcate in the Program a deeply rooted understanding of the goals and values of inclusivity. As described in more detail below, we will monitor the effectiveness of these efforts both internally, via self-evaluations, and via regular input from a professional, outside evaluator. Of particular note, our preliminary studies of like departments and programs at UCSB suggest that UR and non-UR graduate students achieve similar levels of retention in the first three years, but that UR retention rates begin to lag starting in year 4. This highlights the importance of monitoring both “community health” and the progress of individual students throughout the entire arc of a graduate career and remaining ready to intervene at any time if such action is called for. For example, we will require annual dissertation committee meetings with each student after candidacy. During at least a portion of this meeting the advisor will be absent so that our students may more freely discuss their concerns regarding their progress, their relationship with their advisor, and the overall atmosphere of the research group and the Program. If such concerns are identified, the committee will share these and suggested remedies with the Graduate Advisor and Diversity Officer for follow-up. We will also require all trainees to complete and discuss with a member of their committee an annual Individual Development Plan. Such structured self-evaluations of learning and research objectives help to “level the playing field” between students who have received prior training in self-evaluation and those who have not. When combined with more formal Program evaluation (described below), we believe these training program elements will provide important forums for discussing—and monitoring—the effectiveness of our mentoring and advising and the inclusiveness of our Program’s culture.

To maximize the effectiveness of our recruitment, admissions, and training processes we will evaluate these regularly, rigorously, and systematically using both internal surveys and external evaluations. For example, to evaluate—and optimize—our outreach efforts we will: survey applicants to identify the routes by which they learned about the Program; survey the faculty and existing students regarding the contacts and leads they make when they promote the Program; and survey participants in our outreach activities and other activities aimed at improving inclusion. To monitor the success of our admissions efforts we will annually compare our applicant and admission pools with the national percentage of UR students graduating with Engineering Bachelor’s degrees, with the percentage of UR students who apply, who are admitted, and who enroll in all UCSB CoE graduate programs, and with the percentage of UR students

**Posselt, Inside Graduate Admissions: Merit, Diversity, and Faculty Gatekeeping, 2016, Harvard University Press, Cambridge, MA**

††Data from: www.universityofcalifornia.edu/infocenter/doctrnal-rates
who enroll in Engineering graduate programs at peer (AAU and UC) institutions. While we expect much higher UR participation in our applicant pool (as noted above, bioengineering has proven the most diverse engineering subdiscipline), such comparisons will nevertheless serve as a valuable benchmark, providing early warning regarding any problems arising in our recruitment efforts. Concerning Program environment and program inclusivity, the Diversity Officer will perform an annual climate survey of students regarding such retention-relevant issues as their sense of belonging, community, fairness, whether they feel valued, how they participate in meetings, lab work, co-authorship, and their “engineered identities,” all of which are important elements in maintaining high student retention in general, but that have proven particularly important in the retention of UR students. We will likewise monitor retention, average GPA, year to degree, graduation rates, and placement after graduation in order to identify and, if necessary, re-evaluate our and re-direct our efforts.

In addition to the above-described self-evaluations, we will also work with an external evaluator, who will perform more formal assessment of how well we are meeting our diversity and inclusion goals and to collect regular feedback that will be used as the basis for ongoing improvement. To this end we have requested $10k/year for Dr. Lubi Lenaburg to serve as our external evaluator, having oversight on the evaluation and working closely to provide feedback to the Director, Graduate Advisor, and Diversity Officer. Dr. Lenaburg, who is the Evaluation and Assessment Program Manager at UCSB’s Center for Science and Engineering Partnerships, has over 15 years of experience evaluating STEM education and training initiatives such as NSF IGERT, STC PIRE, and LSAMP-BD awards. She brings to these efforts expertise in quantitative methods, survey design, learning assessment, test development, psychometrics, developing successful tracking strategies, and database management and design. At the onset of the Program, we will work with Dr. Lenaburg to define the metrics, survey instruments, and small group ethnographic assessments. Following this we will meet with Dr. Lenaburg regularly for updates on our progress and to evaluate any changes that may be needed to better achieve our goal of building an inclusive, diverse, and equitable Program.

6. Interrelationship of the Program with other University of California institutions

The specific niche we propose to fill is the creation of a degree focused specifically at the interface between engineering and the life sciences, placing synergistic emphasis on the application of engineering principles to the study of biology as a science, and the application of biological principles in the development of new technologies. This focus is captured in the proposed Program name: Biological Engineering. And while all of the existing UC bioengineering-oriented departments conduct research and pedagogy at this interface, a survey of the existing UC graduate offerings in bioengineering, biomedical engineering, and biomolecular engineering (Table 2) suggests that, when coupled with our campus’s unique strengths, the creation of such a Program will provide training and research opportunities to California students that are both in demand and distinct from those currently on offer elsewhere at our University. For example, the sole existing UC department with “biological engineering” as part of its name, Davis’s Department of Biological and Agricultural Engineering, is in a school of agriculture and emphasizes “the production, distribution and processing of biological products.” That is, the focus of the Davis program is narrower than and removed from our emphasis on biology-informed and biology-informing engineering. Likewise, the bioengineering programs on many of our other sister campuses focus heavily on biomedical engineering. Driven by their interactions with their medical schools, the departments at Irvine, Davis, and San Francisco, for example, are formally called Biomedical Engineering (or, in the latter case, Bioengineering and Therapeutic Sciences). And while they have adopted the name “Bioengineering,” the departments at San Diego, Riverside and Los Angeles also focus strongly on biomedical engineering, again due to their understandably close interactions with those campus’s medical schools. The Santa Cruz department and the second departments at Berkeley and Los Angeles, in contrast, are titled Biomolecular Engineering and Chemical and Biomolecular Engineering, respectively, reflecting
the important niche they have chosen to fill, which focuses on the engineering of biomolecules rather than biosystems more generally, and which plays less heed to the pillar of bioengineering focused on the application of the tools and concepts of engineering to advance our understanding of biology. In short, while all of other UC campuses have a presence in the sub-discipline of biological engineering, none focus on it with the depth of the Program we are proposing here.

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<tr>
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<td>agricultural</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irvine</td>
<td>Biomedical</td>
<td>Department</td>
<td>“Applies engineering principles to solve complex medical problems.”</td>
</tr>
<tr>
<td></td>
<td>engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Bioengineering</td>
<td>Department</td>
<td>“At the interface of engineering, medicine, and basic sciences.”</td>
</tr>
<tr>
<td></td>
<td>Chemical and</td>
<td>Department</td>
<td>“For the solution of problems in chemical and biological technology and for the synthesis of innovative (bio)chemical processes and products.”</td>
</tr>
<tr>
<td></td>
<td>Biomolecular</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Merced</td>
<td>Bioengineering</td>
<td>Graduate Program</td>
<td>“To address problems in biology and healthcare; and lessons from biology are used to inspire design and inform progress in engineering.”</td>
</tr>
<tr>
<td>Riverside</td>
<td>Bioengineering</td>
<td>Department</td>
<td>“Impact health and society through research innovation in biotechnology and biomedicine.”</td>
</tr>
<tr>
<td>San Diego</td>
<td>Bioengineering</td>
<td>Department</td>
<td>“Systems biology, regenerative medicine, and multi-scale bioengineering focused on understanding, diagnosis and treatment of human disease.”</td>
</tr>
<tr>
<td>San Francisco</td>
<td>Bioengineering</td>
<td>Department</td>
<td>“High-quality basic, translational, and clinical research in the fields of drug development sciences, pharmacogenomics, therapeutic bioengineering, and computational biology.”</td>
</tr>
<tr>
<td></td>
<td>and Therapeutic</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sciences</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Santa Cruz</td>
<td>Biomolecular</td>
<td>Department</td>
<td>“To address major problems at the forefront of biomedical and bio-industrial research.”</td>
</tr>
<tr>
<td></td>
<td>engineering</td>
<td></td>
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</tr>
</tbody>
</table>

The arguments outlined above are founded on significant interactions with colleagues at our sister campuses. For example, although we do not yet have a graduate program, UCSB has nevertheless actively
participated in the Bioengineering Institute of California (BIC), a research unit that spans bioengineering across all ten UC campuses. Through this Institute the CBE has presented the proposed Program to the wider UC bioengineering community and are happy to note that our sister campuses have been uniformly supportive, both due to the unique nature of the Program we are proposing and because interest in graduate training in bioengineering currently outrrips capacity, particularly in the Southern California area (see support letters from the current and founding chairs of BIC in Appendix C). Through BIC we have also received significant feedback regarding both “best practices” and potential pitfalls, advice that has significantly shaped this proposal.

A note about the obvious: unlike many of our sister campuses, UCSB lacks an associated medical school. We do not, however, consider this a detriment to the proposed Program, but rather an attribute as it limits pressure to move away from more fundamental research and represents a unique niche to attract students who want to work at the intersection of engineering and biology. Nonetheless, the modern tools of collaboration, data sharing, and human stem cell technologies are enabling translational work in any location. For example, CBE Director Pruitt recently collaborated with the UCSB Stem Cell Institute to bring a biobank of isogenic human stem cells to campus to facilitate basic cardiovascular research done in a human genetic background. Likewise, CBE member Dennis Clegg has developed fundamental advances in tissue engineering that are enabling clinical trials of retinal therapies in patients, and CBE member Linda Petzold routinely obtains medical data for her computational analyses. Our local healthcare system (Cottage Hospital) also works closely with our campus to provide access to a vibrant community of doctors eager to support students and faculty members interested in understanding translational clinical challenges.

Synthesizing these arguments, UCSB is uniquely well suited to create a modern, forward-looking Biological Engineering degree that intimately couples engineering and the life sciences. First, the highly collaborative, interdisciplinary ethos of our campus: as evidenced, for example, by the large fraction of our faculty who hold intercollegiative joint appointments bridging between CoE and the sciences. The interdisciplinarity of both our research and our pedagogy have fundamentally shaped our vision of Biological Engineering. Building on this, we have structured the proposed Program to be intra-colligate (CoE and MLPS), which will further facilitate deep links between the life sciences and engineering. Second, unlike campuses with medical schools, which tend to focus on clinical problems, UCSB is well positioned to serve students who seek for research-intensive experiences that more broadly explore the applications of biology to technology and technology to the study of biology. Of note, other top programs without affiliated medical schools (e.g., MIT and CalTech) have likewise leveraged this by founding Departments of Biological Engineering.

7. Department or group that will administer the Program

We are proposing the creation of both a graduate degree (a PhD in Biological Engineering) and an administering Program (the Biological Engineering Program). The Program will span both CoE and MLPS. The Director and Associate Director, who will be appointed by the Deans of CoE and MLPS after consultation with Program faculty, will bear ultimate responsibility for administering the Program, the degree, and the campus’s existing Bioengineering Graduate Emphasis. The nominal terms of office will be three years, which may be renewed. Professor Pruitt has volunteered to serve as Director at the Program’s inception. An Executive Committee, chaired by the Director, will provide general review and guidance on educational policy matters to the leadership (see the proposed bylaws in Appendix D). A Curriculum and Student Affairs Committee will consider policies in all areas of the graduate degree, including financial aid, laboratory rotations, and examinations, and an Admissions Committee will govern admission to the Program, student recruitment, and marketing. The membership of these committees, who will nominally serve for one-year terms, will be appointed by the Director from among Program faculty.
Because Biological Engineering sits squarely at the interface of Engineering and the Life Sciences, it is important that the Program likewise sit at this interface. Thus, our proposal that the Program be intercollegiate and report to, and receive guidance and resources from, the deans of both CoE and MLPS. This said, the degree itself, which is an engineering degree, will be administered solely by the CoE. The FTE of the individual Program faculty members will remain associated with the college of their home departments, and their merits and promotion cases will be routed through this college.

8. **Plan for evaluation of the Program within the offering department(s), Academic Senate and campus wide**

The Program will be evaluated every 10 years by the established campus reviewing mechanism, the Program Review Panel. These reviews will include external reviewers. Internally, the faculty will assess, on a more frequent basis, the curriculum and scope of the Program. Faculty members with non-zero FTE in the Program will be reviewed through the campus’s normal merit and promotion process, while faculty members holding courtesy (0% FTE) appointments will be evaluated for renewal via a similar process every 5 years (see proposed bylaws in Appendix D).
SECTION II. PROGRAM

1. Undergraduate preparation for admission
All applicants must fulfill the general requirements for admission to graduate status. For example, applicants must be on track to receive a bachelor’s degree or equivalent to be considered for admission, but need not hold a master’s degree. Pre-requisite knowledge includes working knowledge of both biology and of engineering concepts and analyses. We anticipate that the majority of applicants will have completed undergraduate degrees in biological engineering degrees and will have this range of training. In addition to such students, however, we place a high value on recruiting exceptional students with degrees in the sciences (e.g., biology, biochemistry) or the other engineering disciplines provided that the appropriate complementary knowledge is obtained prior to starting the Biological Engineering Program. It is not unusual for students with other degrees to have pursued elective courses or equivalent independent study or research giving them sufficient preparation in Math, Physics, Biology, and Chemistry. To be prepared for the first-year core curriculum, we specifically will evaluate students’ pre-requisite knowledge in these areas:

- Physics (minimum of electromagnetism and mechanics)
- Biology (a course covering basic cell biology, molecular biology, genetics and biochemistry)
- At least 1 chemistry course
- Math (through differential equations)
- Programming course or equivalent experience

International students whose native language is not English are required to obtain a minimum score of 550 on the Test of English as a Foreign Language (TOEFL) or 80 on the internet-based test, prior to admission. An exception to the TOEFL requirement is made for students who receive a bachelor’s or master’s degree from an institution in the United States or any other country in which English is the primary language of instruction.

Application will be for the Fall quarter only, with a deadline for applications of December 15. Applicants will be notified of acceptance by April 15.

2. Foreign language
There is no foreign language requirement for this degree

3. Program of study
Figure 4 and Figure 5 provide an overview of the curriculum and timeline for didactic training.

a. Specific fields of emphasis. All enrolled students will complete a unified core curriculum that will serve to train them in the common basis set of knowledge required by the field. To do so, three core courses will expose the students to: 1) experimental methods and quantitative modeling in fluidic and solid biological systems; 2) techniques and data analysis for biomolecular and molecular biology; and 3) experimental design and review of seminar quantitative experiments. All students will also choose a focus area, which provides in-depth knowledge in their chosen sub-field. We envision three such focus areas at the start of the Program, but we anticipate these will evolve over the years and decades as the field and student and faculty interests evolve. The initial three are: 1) Biological Modeling and Signal Processing, 2) Synthetic Biology and Biomolecular Engineering, or 3) Cell, Tissue and Device Engineering. The courses for these focus areas are described below with their relation to the curriculum detailed in Figure 5.
a. **Degree Plans**

**PhD:** A four-member committee, including the dissertation advisor, with mandatory oral defense.

**Master of Science:** Admission will only be to the PhD Program. This said, following the completion of a Master’s thesis (MS Plan-I Thesis) approved by a four-member committee, a Master’s Degree may be awarded to: (1) students who have completed the relevant unit and coursework requirements and have elected to leave the PhD program or (2) continuing students who completed the relevant unit and coursework requirements, have advanced to candidacy, and request the MS degree.

b. **Units Requirements.** The requirements for the PhD and MS degrees in Biological Engineering include the completion of 36 units of coursework. This is consistent with other UC Bioengineering graduate programs: UC Riverside requires 36 units, UC Merced requires 32, and UC Davis requires 40. MS students must maintain a GPA of at least 3.0 and per Senate policy, MS students must maintain a letter grade of C or better in the Core courses and Focus Area Courses (23 units) PhD Students must maintain a GPA of at least 3.5 from the Core courses and Focus Area courses (23 units) to take the qualifying exam.

c. **Curriculum including required and recommended courses.** As described below, the curriculum consists of didactic training, research rotations, technology transfer exposure, teaching experiences, seminar presentation training and experiences, and completion of a research proposal and dissertation.

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**Figure 4.** Proposed timeline for completion of required coursework.

**Figure 5.** The proposed curriculum, with existing, non-core courses denoted in white; these will be cross-listed between the Program and the home departments of responsible faculty members (see text).
The didactic curriculum is comprised of: Three required core courses (11 units) in the first year of study and four additional courses (min. 12 units) with at least two drawn from a focus area, at least one from a different focus area, and one additional science or engineering elective. All students will also complete training in bioethics and the responsible conduct of research (1 unit). Finally, the program seeks to provide training in the application and translation of engineering design. Thus, all students will choose to a) take an existing course in biomedical/pharmaceutical devices and translation (3 units), or b) complete an industry internship, or c) participate in approved activities that provide exposure to industry and translational applications of Biological Engineering (e.g., Biomedical Engineering Society student chapter tours, biotechnology industry showcase, internships). If students choose the latter, the proposed program of activities will be approved by the Graduate Coordinator. The timeline for the didactic components of the program are presented graphically in Figure 4.

i. Research Rotations: First-year research rotations (1 unit per quarter), which serve to promote interdisciplinary training and collaboration, are a near universal component of bioengineering graduate programs. Students in the Biological Engineering Program will participate in four different mini-rotations in the Fall quarter (at least 3 of which are performed in Program faculty member labs, including those of the Affiliated Faculty) to identify projects for quarter-long research rotations during the Winter and Spring quarters of their first year. The deliverables from the mini-rotations include a logbook of proposed projects and a preference ranking for which labs they would like to join for Winter and Spring research rotations. The Winter quarter rotations will be conducted in conjunction with the core course on Great Experiments – students will team up to collaborate on joint projects across their research rotation labs with support on experiment design, team management and project planning from the course instructors and their research rotation PIs. The Spring quarter rotation will proceed independently. Based on these experiences, our students will submit lab preferences and be matched to a research lab by their first Summer.

ii. Teaching: To provide teaching experience and demonstrate mastery of knowledge fundamental to bioengineering, students will complete at least 2 quarters as a teaching assistant in a course related to their field of study. TA assignments will be arranged by the graduate committee, who will canvas relevant cognate departments to best match campus needs with student skills and interests. Of note, many of our campus’s existing departments (e.g., Molecular, Cellular and Developmental Biology, Chemistry and Biochemistry) struggle to find sufficient trained graduate students to fulfill TA needs in biology-oriented classes. The cohort of TAs provided by the proposed Program will help to fill this increasingly pressing need.

iii. Yearly enrollment in the Biological Engineering Graduate Seminar for a minimum of 2 years and presentation of one seminar per year (6 units);

iv. Yearly enrollment in Directed Reading and Research (before advancement to candidacy) or PhD Dissertation Preparation (after advancement to candidacy);

v. Satisfactory performance on the qualifying exam (described below) by the end of the second year.


4. Field Examinations

None

5. Qualifying examination

The PhD qualifying process will include a Dissertation Proposal Presentation, which will serve as an Oral Qualifying Exam. This will consist of a written thesis proposal, an oral defense of this proposal, and an oral examination by the pre-candidacy thesis committee. This committee is comprised of at least four
academic senate faculty members: a chair, who is selected from among the Program faculty by the Graduate Advisor, and three or more faculty members selected by the student, at least one of whom is a member of the Program faculty. To ensure the freest possible communication between Program students and their committees, the thesis advisor is explicitly excluded from direct service on the examination committee.

In the exam, students must demonstrate broad knowledge of the field of Biological Engineering, superior competence in the areas of specialization related to their research, and satisfactory knowledge of science and engineering areas relevant to the dissertation topic.

6. **Dissertation**

A written dissertation is required, which must demonstrate the student’s ability to contribute significantly and independently to the field. This will be guided by a dissertation committee comprised of at least four academic senate faculty members, at least two of who are members of the Program. This nominally consists of the members (but not the chair) of the qualifying exam committee plus the student’s thesis advisor, who serves as chair of this committee. This committee is the ultimate judge of the merit of the completed dissertation. Approval of this dissertation by each member of the doctoral committee is thus required for conferral of the degree.

7. **Dissertation Defense/Final Exam**

A public defense of the dissertation will be required. This 45-minute seminar will be followed by an open question period, then a closed-session question period with the dissertation committee. Students must submit a dissertation of suitable quality to the dissertation committee prior to scheduling their defense to ensure the committee has time to review the document.

8. **Sample Program**

Year 1: Completion of core curriculum and research rotations
- Fall: two core courses (7 units) and four 2-week mini-rotations (1 unit). The deliverables from these mini-rotations is a logbook of proposed projects and a preference ranking for which labs they would like to join for Winter and Spring research rotations
- Winter: one core course (4 units) and first research rotation (1 unit). This rotation will be conducted in conjunction with the core course on Great Experiments – students will “team up” to collaborate on joint projects across their research rotation labs with support on experiment design, team management and project planning from the course instructors and their research rotation mentors
- Spring: second rotation (1 unit) and first focus area course (3 units)
- Summer: matching with research lab and begin dissertation research

Year 2: Two focus area courses or 1 focus area course and 1 elective (6 units)
- Biological Engineering Graduate Seminar and presentation of one seminar per year (1 unit)
- Responsible Conduct of Research/Bioethics (1 unit)
- Enrollment in Directed Reading and Research (before advancement to candidacy) or PhD Dissertation Preparation (after advancement to candidacy)

Year 3. Any additional elective courses or focus area courses (3 units)
- First (at least annual) dissertation committee meeting
- Biological Engineering Graduate Seminar and presentation of one seminar per year (1 unit)
- Pharmaceutical/Industry course or Industry Internship (3 units)
- Enrollment in Directed Reading and Research (before advancement to candidacy) or PhD Dissertation Preparation (after advancement to candidacy)
Year 4. Enrollment in PhD Dissertation Preparation
   - Biological Engineering Graduate Seminar and presentation of two seminars per year (2 units)

Year 5: Dissertation committee meeting
   - Biological Engineering Graduate Seminar and presentation of one seminar per year (1 unit)
   - Enrollment in PhD Dissertation Preparation

Year 6: Complete dissertation defense seminar
   - Biological Engineering Graduate Seminar and presentation of one seminar per year (1 unit)
   - Enrollment in PhD Dissertation Preparation

9. **Normative Time from matriculation to degree**
   The normative time to degree is expected to be six years. The normative duration for pre-candidacy is three years, with students expected to complete their qualifying examination in Spring of their third year.
SECTION III. PROJECTED NEED

1. Student demand for the Program

This proposal is in direct response to significant and growing student demand for graduate training in biological engineering both across California in general and on our campus specifically. For example, although existing CoE departments and the Biomolecular Science and Engineering (BMSE) program interview a number of strong, bioengineering-oriented graduate applicants every year, few accept our offers of enrollment due to a lack of bioengineering focus in the existing curricula, and the limited focus on bioengineering in any single existing department. In short, despite the availability of our Graduate Emphasis in Bioengineering and the large number of distinguished UCSB faculty members with expertise in biological engineering we continue to lose top tier student applicants with interests centered at the interface of engineering and the life sciences to institutions with formal bioengineering programs. At the state level, the demand for bioengineering training is robust; enough so that the bioengineering programs on our sister campuses are turning away large numbers of applications (Table 3) Simply put, it is clear that, backed by UCSB’s strong (and growing stronger) research programs in biological engineering, the Biological Engineering graduate degree proposed here will attract a strong and diverse cohort of graduate students to our campus.

<table>
<thead>
<tr>
<th>Table 3. UC Bioengineering program admission rates</th>
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<tbody>
<tr>
<td>Applied</td>
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<tr>
<td>---------</td>
</tr>
<tr>
<td>UC Berkeley/UCSF</td>
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<tr>
<td>UC Davis</td>
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<tr>
<td>UC Irvine</td>
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<tr>
<td>UCLA</td>
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<tr>
<td>UC Merced</td>
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<tr>
<td>UC Riverside</td>
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<tr>
<td>UC Santa Cruz</td>
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<tr>
<td>UC San Diego</td>
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<tr>
<td><strong>Totals</strong></td>
</tr>
<tr>
<td>UCSB (Graduate, across all of CoE)</td>
</tr>
</tbody>
</table>

2. Opportunities for placement of graduates

Graduates of the proposed Program will find employment as teachers, researchers and administrators in a job market that is already healthy and only continues to grow. For example, the Bureau of Labor Statistics predicts 10% growth in California bioengineering jobs over the decade from 2016.‡‡ Bioengineers are prized for core skills in interdisciplinary problem solving and managing complex projects. Thus, the interdisciplinary and collaborative nature of the first-year curriculum with its focus on experiment and project design, is designed not only to build depth and breadth, but to foster the leadership, teamwork and communication skills essential for bioengineers to succeed in industry and, increasingly, in academia.

‡‡https://www.bls.gov/ooh/architecture-and-engineering/biomedical-engineers.htm
A major goal of the proposed Program is to enhance career options and broaden student horizons. The common core and specialization courses we have proposed are designed with this in mind, and will provide the depth and breadth of knowledge expected of graduates in biological engineering. We note that UCSB is already training graduate students who enter the bioengineering job market. The proposed new Program will increase these numbers, but primarily its goal is to attract and train students with a focused yet interdisciplinary curriculum, and with a degree title that reflects their training. The opportunities for bioengineers are expanding as the number of biotechnology companies and applications continue to grow.

3. Importance to the discipline

Biological Engineering provides a powerful bridge between sciences and engineering. The proposed biological engineering Program is designed to give students the knowledge from both the science and engineering disciplines in order to successfully solve engineering problems in biological systems. Biological engineering’s most visible branch is often biomedical engineering, however biological engineering crosses into many areas that may not always be considered traditional engineering or biological disciplines, such as environment, renewable fuel sources, sustainable systems, agriculture, and stem cell and tissue engineering. The existing Emphasis interfaces with 13 different disciplines on campus, and similarly, the Program will benefit cross-disciplinary training opportunities. Biological Engineering will train students in fundamental discovery, experimental methods, quantitative analysis, and technological design, innovation and application and prepare them for careers in all areas of biological engineering.

4. Ways in which the Program will meet the needs of society

Investment in the proposed Biological Engineering degree would be a timely response to important social and civic needs. Ongoing advances in, for example, biotechnologies, green technologies and, of course, biomedicine, are creating strong demand for individuals who are educated not only in fundamentals of engineering, but also in the life sciences. In support of this claim, we note again that the Bureau of Labor Statistics predicts 10% growth in bioengineering jobs in California between 2016 and 2026.

5. Relationship of the Program to research and/or professional interests of the faculty

The proposed Program is well aligned with the research interests of a large (and rapidly increasing) fraction of UCSB’s faculty. Indeed, despite lacking a department or even a graduate degree in any aspect of bioengineering, UCSB has become a world-class center of excellence in research in this discipline. Using deep knowledge of the materials and mechanisms employed in biology, research at UCSB is yielding important advances in biofuel production (O’Malley, Chemical Engineering; Abu-Omar, Chemistry and Biochemistry), in-vivo molecular sensing (Plaxco, Chemistry and Biochemistry; Mukherjee, Chemical Engineering), haptics (Visell, Electrical and Computer Engineering), and advanced, adaptive and even self-healing materials (Morse and Waite, Molecular, Cellular and Developmental Biology; Pitenis, Materials; Fyngenson, Physics; Stowers, Mechanical Engineering). Designing new tools, assays and technologies, bioengineering research on campus is enabling quantitative biological experiments and computational modeling to understand the rules of life (Campas, Doyle, Dressaire, McMeeking, Petzold, Pruitt, Stowers, Valentine, and Yeung, Mechanical Engineering; Dey, Chemical Engineering; Clegg, Louis, and Wilson, Molecular, Cellular and Developmental Biology; Dogic, Marchetti, Shraiman, and Streichan, Physics), and for translational applications to the life sciences (Pennathur, Mechanical Engineering; Theogarajan and Smith, Electrical and Computer Engineering; Clegg, Molecular, Cellular and Developmental Biology).

The existing research strengths of UCSB guided the selection of the focus areas we propose to “round out” our Biological Engineering curriculum. The Synthetic Biology and Molecular Engineering focus area, for example, reflects multiple, major research efforts on our campus, whereby new functions are being created by a novel combination of biological parts. UCSB researchers in synthetic biology are
designing synthetic enzyme complexes, and evolving novel intracellular regulatory systems. Research within this focus area is likewise supported by the Institute of Collaborative Biotechnologies, which includes “Systems and Synthetic Biology” as a research priority area. The Biological Modeling and Signal Processing focus, in turn, builds directly on UCSB’s well-recognized strengths in physics, bioinformatics, and engineering. This area also leverages the campus’s existing strengths in computational science at various scales starting from molecular simulations to cellular and neurological signal processing and organism-level modeling. Research in the Materials Research Lab and Institute of Collaborative Biotechnologies has already established core expertise in the field of synthesis, characterization and applications of bio-organic and bioinorganic materials. Collaborations between biologists and materials scientists feed the modern field of tissue engineering and regenerative medicine. This field also benefits from the expertise on campus in stem cells, located primarily in the Stem Cell Center. The Cell, Tissue and Device Engineering focus builds on UCSB’s strengths in the areas of biomaterials, mechanobiology, sensing, and genetic engineering, areas that especially active within the Institute for Collaborative Biotechnologies, Neuroscience Research Institute, and Stem Cell Institute. Collectively, these activities are poised to establish UCSB’s pioneering efforts in the engineering of cells, devices and biomaterials with materials and interfaces designed for and derived from biology.

Given the above, we are confident that the Program will be well served by the exceptional communication and cross-disciplinary work on our campus between CoE and MLPS. For example, with its genesis as an inter-departmental Program the Program can and will leverage resources (both faculty and otherwise) not only from all of CoE’s world-caliber departments but also from key MLPS departments. Moreover, the proposed degree will, in turn, help build yet stronger bridges between the contributing departments and colleges, and provide a critical training ground for existing and future students.

6. Program differentiation

At the campus level, the proposed graduate degree will augment existing educational efforts by creating new courses that will be of interest to students enrolled in many of the college’s existing graduate degrees. From our discussions with the existing CoE departments we have learned that many are under pressure to offer new elective courses in bio-related fields. The new courses proposed here, which we anticipate will be made available to other graduate students will address this. As an informative precedent, the courses created in support of CBE’s Graduate Emphasis in Bioengineering are open to all graduate students interested in bioengineering (i.e., not just those enrolled in the Emphasis), providing opportunities that have, for example, supported significant curricular reforms in both Chemical and Mechanical Engineering, each of which now allows their graduate students to take these courses as electives and even as core courses.

The proposed program will also augment current graduate offerings across the entire UC system. While the comparatively late introduction of a bioengineering major at UCSB relative to the other UC campuses (Table 4) could be perceived as a disadvantage, we have leveraged this opportunity to benchmark other programs. Having studied the programs at our peer institutions in detail, we have put together a unique degree program that will distinctly position us and give us advantages in recruiting students interested in merging biological sciences and engineering for fundamental research and innovative applications. First, the highly interdisciplinary nature of research at UCSB strongly impacts our pedagogy, rendering our campus particularly well placed to create a biological engineering degree. Moreover, starting out as an intra-departmental Biological Engineering Program provides strong links between this degree and the more traditional fields of engineering and sciences. Second, unlike campuses with medical schools that have a clinical focus and large numbers of premed students, UCSB is well positioned to serve students who seek to explore the field more broadly than is possible at institutions with a heavily biomedical focus. For example, UCSB is home to several world-class research centers, including, for example, the Institute for Collaborative Biotechnologies, the Materials Research Laboratory, the California
NanoSystems Institute, and the Neuroscience Research Institute, born of the focused research expertise of our faculty, including many of the bioengineering-oriented faculty members on our campus.

<table>
<thead>
<tr>
<th>Campus – Academic Unit</th>
<th>Degrees offered</th>
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</table>
| UC Berkeley – Department of Bioengineering | BS in Bioengineering  
ME and PhD in bioengineering (joint w/ UCSF)  
ME and PhD in Translational Medicine (joint w/ UCSF) |
| UC Berkeley – Department of Chemical and Biomolecular Engineering | BS in Chemical Engineering; Chemical Biology  
MS and PhD in Chemical Engineering  
MS in Bioprocess Engineering |
| UC Davis – Department of Biomedical Engineering | BS in Biomedical Engineering  
MS and PhD in Biomedical Engineering |
| UC Davis – Department of Biological and Agricultural Engineering | BS in Biological Systems Engineering  
MS, MEng, PhD and DEng in Biological Systems Engineering |
| UC Davis – College of Biological Sciences | PhD in Biophysics  
MS and PhD in Biochemistry, Molecular, Cellular and Developmental Biology  
MS and PhD in Chemistry; emphasis in Biotechnology |
| UC Davis – Department of Chemistry | MS and PhD in Chemistry; emphasis in Biotechnology |
| UC Davis – Graduate Group in Immunology | MS and PhD in Immunology; emphases in Biotechnology, Translational Research |
| UC Irvine – Department of Biomedical Engineering | BS in Biomedical Engineering  
MS and PhD in Biomedical engineering |
| UC Los Angeles – Department of Bioengineering | BS in Bioengineering  
MS and PhD in Biomedical Engineering |
| UC Los Angeles – Department of Chemical and biomolecular engineering | BS in Chemical Engineering; Biomolecular Engineering specialization  
MS and PhD in Chemical Engineering |
| UC Merced – School of Engineering | BS degree in Bioengineering  
MS and PhD in Biological Engineering and Small-scale Technologies |
| UC Riverside – Department of Bioengineering (plus Interdepartmental graduate Program) | BS in Bioengineering  
MS and PhD in Bioengineering |
| UC Santa Barbara | None |
| UC Santa Cruz – Department of Biomolecular engineering | BS in Bioengineering  
BS in Bioinformatics  
MS and PhD in Biomolecular Engineering and Bioinformatics  
PhD in Chemical Biology, Biochemistry and Biophysics  
PhD in Microbial Biology and Pathogenesis  
PhD in Molecular, Cell and Developmental Biology |
| UC San Diego – Department of Bioengineering | BS in Bioengineering  
BS in Biotechnology  
BS in Bioinformatics  
MS and PhD in Bioengineering; Multiscale Bioengineering, Tissue Engineering and Regenerative Medicine, Systems Biology and Medicine |
| UC San Francisco – Department of Bioengineering and Therapeutic Science | PhD in bioengineering (joint w/ Berkeley) |
SECTION IV. FACULTY

Our intention is that the Biological Engineering Program will, within two years of its launch, include 12 “Core Faculty” members drawn from the current faculty in three CoE departments and three MLPS departments (Table 6) and 11 “Affiliated Faculty” (0%) faculty (Table 5) for a total of 23 faculty providing both potential homes for our graduate students and courses to fulfill the proposed curriculum. In addition, we are requesting 6 additional FTE (some of who will presumably be joint hires with existing departments and programs) over the first six years of the program.

| Table 5. Affiliated Faculty (0%) who have committed to cross list courses in support of the curriculum |
|--------------------------------------------------|--------------------------------------------------|
| Michael Beyeler                                  | Assistant Professor, Computer Science/Psychology and Brain Sciences |
| Zvonimir Dogic                                   | Professor, Physics |
| Emilie Dressaire                                 | Assistant Professor, Mechanical Engineering |
| Matthieu Louis                                   | Assistant Professor, Molecular, Cellular and Developmental Biology |
| Cristina Marchetti                               | Professor, Physics |
| Linda Petzold                                    | Professor, Mechanical Engineering and Computer Science |
| Angela Pitenis                                   | Assistant Professor, Materials |
| Omar Saleh                                       | Professor, Materials |
| Luke Theogarajan                                 | Professor, Electrical and Computer Engineering |
| Yon Visell                                       | Associate Professor, Electrical and Computer Engineering/Media Arts and Technology |
| Enoch Yeung                                      | Assistant Professor, Mechanical Engineering |

The Core Faculty will consist of 12 current UCSB faculty members, each of whom have agreed to transfer 50% of their FTE into the Program after its launch (see letters of commitment in Appendix E). Our purpose in requesting such 50% FTE transfer is based on significant prior campus experience and represents a tradeoff between sufficient commitment to ensure the success of the curriculum and our effort to minimize any potential negative impact on the current home departments of these faculty members. We note again, however, that many of the relevant faculty members were hired under the explicit assumption that they would, in the future, be transferring significant portions of their FTE to this Program. At 50% commitment, for example, faculty members will be in a position to annually teach one course in their primary department, one in the Program, and a third that benefits both the Program and their home department, such as a cross-listed elective. The resulting high level of faculty member engagement will not only enable the efficient launch of a healthy graduate program, but also position us to move nimbly to establishing a department and, eventually, an undergraduate degree as logical next

| Table 6. Core Faculty who have committed to the transfer of FTE into the Program |
|----------------------------------|----------------------------------|
| Beth Pruitt                      | CBE Director and Professor, Mechanical Engineering/BMSE |
| Kevin Plaxco                    | CBE Associate Director and Professor, Chemistry and Biochemistry/BMSE |
| Otger Campus                    | Associate Professor, Mechanical Engineering |
| Dennis Clegg                    | Professor, Molecular, Cellular and Developmental Biology/BMSE |
| Siddarth Dey                    | Assistant Professor, Chemical Engineering |
| Adele Doyle                     | Assistant Professor, Mechanical Engineering |
| Arnab Mukherjee                 | Assistant Professor, Chemical Engineering |
| Michelle O’Malley               | Associate Professor, Chemical Engineering |
| Spencer Smith                   | Associate Professor, Electrical and Computer Engineering |
| Ryan Stowers                    | Assistant Professor, Mechanical Engineering |
| Sebastian Streichan             | Assistant Professor, Physics/BMSE |
| Max Wilson                      | Assistant Professor, Molecular, Cellular and Developmental Biology |
steps. After the Program is established, concomitant with the transition to a department structure and undergraduate program proposal, we anticipate that several faculty members will move majority appointments to the new department.

We will stage the necessary FTE transfers to minimize any negative impact on the existing departments and their teaching responsibilities. This is especially true for the junior faculty members who have committed to becoming core Program faculty: all involved stakeholders recognize that the success of our junior and mid-career faculty members is a top priority and will endeavor to ensure this success is achieved. We include letters of commitment from core members for the new Program who plan to facilitate the curriculum by teaching to the Program benefit as described above. These faculty members are not only committed to training the graduate student cohorts in the Program, but also to efforts to develop and expand curricular options for undergraduate programs on campus. Should a conflict arise regarding service assignments or the “split-quarter” teaching of 50% FTE faculty, the faculty will decide between the options proffered by the two departments. We note, however, that we do not expect any such conflicts to arise; none have arisen, for example, during the more than 20 years that CBE Associate Director Plaxco has spent split 50/50 between BMSE and Chemistry and Biochemistry.

The eleven “Affiliated Faculty,” who will have 0% “courtesy” appointments (listed in Table 5) will provide further research opportunities for Program students and will help to ensure our curricular offerings are plentiful and diverse. The appointments of these faculty will be for five-year renewable terms (see the proposed bylaws in Appendix D). And while these colleagues have not (yet) committed FTE to the Program, all are committed in their interest in teaching (in the classroom) and mentoring (in their laboratories) Program students (see letters of commitment in Appendix E). With regard to the former, each of the Affiliated Faculty already teaches one or more courses in their home departments that are congruent with the proposed curriculum (Table 7), and each has committed to teaching these courses at least every other year during the first five years of the Program. Likewise, they and their department chairs have agreed that these courses will be open to Program students as focus area courses (as noted in the departmental and faculty letters of support in appendices B and E). Moving forward, additional faculty members who may wish to join the Program as 0% FTE transfers after its inception may be added on approval as described in the proposed bylaws (Appendix D).
SECTION V. COURSES

The existing and proposed core, focus area (Figure 5) and elective courses in the curriculum, along with their proposed instructors, are listed in Table 7.

<table>
<thead>
<tr>
<th>Table 7. Program courses (courses to be taught by Core Faculty denoted in bold)</th>
<th>Instructor(s)</th>
<th>Existing or newly proposed course?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. REQUIRED CORE COURSES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomolecular and Biochemical Methods</td>
<td>Plaxco, Mukherjee</td>
<td>BIOE (New)</td>
</tr>
<tr>
<td>Quantitative Experiments</td>
<td>Wilson, Dey</td>
<td>BIOE (New)</td>
</tr>
<tr>
<td>Great Experiments</td>
<td>Pruitt, Streichan</td>
<td>BIOE (New)</td>
</tr>
<tr>
<td><strong>B. BIOLOGICAL MODELING AND SIGNAL PROCESSING FOCUS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physics of Living Matter</td>
<td>Streichan, Shraiman</td>
<td>PHYS250</td>
</tr>
<tr>
<td>Basic Microscopy for Quantitative Biology</td>
<td>Streichan</td>
<td>BMSE219</td>
</tr>
<tr>
<td>Optics and Imaging</td>
<td>Smith</td>
<td>ECE594Q</td>
</tr>
<tr>
<td>Neuroengineering; measuring &amp; manipulating activity</td>
<td>Smith</td>
<td>ECE (New)</td>
</tr>
<tr>
<td>Biological Dynamics</td>
<td>Wilson</td>
<td>MCDB172</td>
</tr>
<tr>
<td>Applied Machine Learning/Big Data</td>
<td>TBD</td>
<td>BIOE (New)</td>
</tr>
<tr>
<td>Signal Processing in Biology</td>
<td>TBD</td>
<td>BIOE (New)</td>
</tr>
<tr>
<td><strong>C. COMPUTATIONAL, SYNTHETIC AND SYSTEMS BIOLOGY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Approaches to Systems Biology</td>
<td>Dey</td>
<td>CHE154</td>
</tr>
<tr>
<td>Omics Enabled Biotechnology</td>
<td>O’Malley</td>
<td>CHE 272</td>
</tr>
<tr>
<td>Model-Guided Engineering of Biological Systems</td>
<td>Mukherjee</td>
<td>ChE174</td>
</tr>
<tr>
<td>Bioinformatics/Genomics</td>
<td>TBD</td>
<td>BIOE (New)</td>
</tr>
<tr>
<td>Molecular Engineering</td>
<td>TBD</td>
<td>BIOE (New)</td>
</tr>
<tr>
<td>I/O Hacking Biology</td>
<td>TBD</td>
<td>BIOE (New)</td>
</tr>
<tr>
<td>Synthetic Biological Design, Control and Computing</td>
<td>Yeung</td>
<td>ME225EY</td>
</tr>
<tr>
<td>Numerical Simulation (in Biology)</td>
<td>Petzold</td>
<td>CS211B</td>
</tr>
<tr>
<td><strong>D. CELL, TISSUE AND DEVICE MECHANICS AND ENGINEERING</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomaterials and Biosurfaces</td>
<td>Pitenis</td>
<td>MATRL270</td>
</tr>
<tr>
<td>Engineering Biomaterials</td>
<td>Stowers</td>
<td>ME225RS</td>
</tr>
<tr>
<td>Methods in Mechanobiology and Biofabrication</td>
<td>Pruitt</td>
<td>ME225BP</td>
</tr>
<tr>
<td>Structure and Function of Biological Materials</td>
<td>Plaxco, Stowers</td>
<td>BIOE (New)</td>
</tr>
<tr>
<td>Cell and Tissue Engineering</td>
<td>Doyle, Clegg</td>
<td>BIOE (New)</td>
</tr>
<tr>
<td>Pattern Formation &amp; Self-Organization</td>
<td>Campas</td>
<td>ME211</td>
</tr>
<tr>
<td>Physics and Mechanics of Multicellular Systems</td>
<td>Campas</td>
<td>ME (New)</td>
</tr>
<tr>
<td><strong>E. ELECTIVES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical Force and Biomaterials</td>
<td>Saleh</td>
<td>MATRL272</td>
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<tr>
<td>Haptics</td>
<td>Visell</td>
<td>ECE594T</td>
</tr>
<tr>
<td>Introductory Bioelectronics</td>
<td>Theogarajan</td>
<td>ECE (New)</td>
</tr>
<tr>
<td>Soft Matter Physics</td>
<td>Dogic, Marchetti</td>
<td>PHYS (New)</td>
</tr>
<tr>
<td>Bio-inspired design</td>
<td>Dressaire</td>
<td>ME (New)</td>
</tr>
<tr>
<td>Computational methods in behavior</td>
<td>Louis</td>
<td>MCDDB (New)</td>
</tr>
<tr>
<td>Bionic vision</td>
<td>Beyeler</td>
<td>CS (New)</td>
</tr>
<tr>
<td><strong>F. ADDITIONAL REQUIREMENTS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bioethics and Responsible Conduct of Research</td>
<td>Currently online</td>
<td>BIOE (New)</td>
</tr>
<tr>
<td>Biomedical Devices</td>
<td>Steve Laguette</td>
<td>ME128</td>
</tr>
<tr>
<td>Pharma translation</td>
<td>Clegg</td>
<td>MCDB294</td>
</tr>
<tr>
<td>Industrial Internship Experience</td>
<td>Staff/Grad advisor</td>
<td>BIOE (New)</td>
</tr>
</tbody>
</table>
Syllabi (existing or proposed) for these courses are included as Appendix F. A degree sheet is provided as Appendix G. The descriptions of the relevant courses are as follows and course numbers are provided for existing courses.

A. Required and core courses

**BIOEXXX Biomolecular and Biochemical Methods:** The goal of the course is to generate in our students and understanding of the logic behind the key tools used to characterize biomolecules and biosystems. Both the mechanisms by which these techniques work, and the rational for why each would be employed (strengths, weaknesses, potential pitfalls).

**BIOEXXX Quantitative Experiments:** This course is centered around experiment/analysis workflow and case studies of: Designing an Experiment-Experimental design considerations and a priori assumptions. Topics include Probability (concept of power), sampling noise, DOE, Mutual information and dimensional reduction, selection of appropriate controls and null hypothesis, analyzing data and testing hypotheses. Students will learn the use of statistics (distributions, parametric, \(\mu, \sigma, x, s, t\)-test, ANOVA) and when to use non-parametric analyses. Students will review of papers with good and bad experimental and/or statistical design.

**BIOEXXX Great Experiments:** This course introduces students to seminal experiments that introduced pioneering biological engineering methods and experimental analysis. Students will learn the principles of sound experimental design to test a hypothesis, become familiar with techniques using bacterial and stem cell model systems, as well as imaging and analysis methods.

B. Biological modeling and signal processing focus

**PHYS250 Physics of Living Matter:** This course is the first part of two quarter course focused on the physics of living matter (with the second part to be taught in the Winter quarter). We will analyze physical phenomena involved at different scales in the process of building an embryo. You may think that animal (or plant) development is a problem of biology. But morphogenesis - generation of form – holds equally exciting question for physics. For example, addressing the question “How does DNA encode shape?” involves ideas and concepts from physics at all levels. The first part will focus on molecular and single cell-scale phenomena. The second part will address behavior of cell collectives, and mechanisms and mechanics of pattern and shape formation.

**BMSE219 Basic Microscopy for Quantitative Biology:** Fluorescence live imaging is a powerful tool to study dynamics of living matter. This course provides an overview on geometric and Fourier optics, bright field microscopy, and fluorescence and absorption spectroscopy. Practicing these concepts students will construct a light-sheet microscope.

**ECE594Q Optics and Imaging:** In this course, students will learn how to build and analyze optical pathways, how to acquire multi-scale, three dimensional and time resolved imaging data, how to denoise, align, segment and reconstruct 3D structures from planar image scans. (New course, to be developed.)

**ECE594 Neuroengineering; Measuring and Manipulating Activity:** Fundamental research into brain function can inform neurobiology, artificial intelligence, and lead to advances in clinical therapies and brain-machine interfaces. Measuring and manipulating brain activity, across hundreds or thousands of neurons with the resolution of individual neurons, is challenging. It involves state-of-the-art engineering in an array of disciplines including optics, protein engineering, imaging, and electronics. We will cover the latest technology for these aspects of neuroengineering, and the prospects for further advances.

**MCDB172 Biological Dynamics:** This course is an introduction to mathematical models and computer simulations used to describe and understand time varying biological systems.

**BIOEXXX Applied Machine Learning/Big Data** We expect this class to be developed and taught by a new FTE hire. Machine learning has potential in to analyze large, complex biological data sets. It is used
often a pivotal tool in computational biology and bioinformatics. However, biological information is required in addition to machine learning for successful application. This class will focus on how big data/applied machine learning can be used for image processing and segmentation, genomics, proteomics, microarrays and systems biology. (New course, to be developed.)

**BIOEXXX Signal Processing in Biology:** We expect this class to be developed and taught by a new FTE hire. This course will be designed to introduce two fundamental concepts of signal processing: linear systems and stochastic processes. Various estimation, detection and filtering methods are developed and demonstrated on biomedical signals. The methods include harmonic analysis, auto-regressive modeling, Wiener and Matched filters, linear discriminants, and independent components. All methods will be developed to answer concrete question on specific data sets in modalities such as ECG, EEG, MEG, Ultrasound. (New course, to be developed.)

**C. Computational, synthetic and systems biology**

**CHE154 Engineering Approaches to Systems Biology:** Applications of engineering tools and methods to solve problems in systems biology. Emphasis is placed on integrative approaches that address multi-scale and multi-rate phenomena in biological regulation. Modeling, optimization, and sensitivity analysis tools are introduced.

**CHE 272 “Omics” Enabled Biotechnology:** This course will integrate genomic, transcriptomic, metabolomic, and proteomic approaches to quantify and understand intricate biological systems. Complementary bioinformatics approaches to curate the large datasets associated with these experiments will also be discussed. Recent examples from the literature will reinforce core concepts, ranging from applications to human health to the environment. By the end of the course, you should be able to design an integrated experiment that capitalizes on these “omics”-based approaches to enhance the scope of your own research.

**CHE174 Model-Guided Engineering of Biological Systems:** This course will introduce students to fundamental principles underlying synthetic biology with an emphasis on mathematical modeling of gene regulation using ordinary differential equations and mass action kinetics. Students will be introduced to foundational concepts in molecular and cellular engineering, synthetic biology, quantitative modeling of various genetic circuits, as well as cutting edge applications of innovative molecular biotechnologies such as cancer immunotherapy and cell-based diagnostics. Students will also learn to design and predict the functional outcomes of synthetic gene circuits and review primary literature in the field. At the end of this course, students are expected to develop a quantitative understanding of genetic circuit design as well as understand how a quantitative engineering-focused approach to the life sciences is driving entirely new advances in the healthcare, security, and manufacturing sectors.

**BIOEXXX Bioinformatics/Genomics:** We expect this class to be developed and taught by a new FTE hire. Students will learn to navigate major bioinformatics databases such as reference genomes, GEO, or Biomodels and define the identifying systems for one or more bioinformatics pathways relevant to their interests (e.g., Accession Numbers, Gene Ontology IDs, KEGG Identifiers, etc.). Students will learn to determine variation between two individuals at the single gene and at the genomic level and learn to design primers to manipulate a specific gene for different downstream applications (e.g., molecular engineering in mutation sites; measuring expression with quantitative PCR) At the end of the course students should be able to read and construct plasmid maps and restriction digest maps as well as read and interpret reference sequence data from NCBI Nucleotide database. They will be expected to analyze next generation sequencing data, from raw data input to the computational pipeline through quantification of expression differences and visualization of results and identify and interpret epigenetic or chromatin signatures from experimental data. (New course, to be developed.)
**BIOEXXX Molecular Engineering:** We expect this class to be developed and taught by a new FTE hire. Students will learn to recognize the various techniques for engineering the structures of biomolecules and identify potential sites for of bio-orthogonal modification. The class will demonstrate how structural and electrochemical properties of single molecules predict their higher-order assemblies, and describe the biomedical and biomanufacturing applications of purpose-built biomolecules. (New course, to be developed.)

**BIOEXXX I/O Hacking Biology:** We expect this class to be developed and taught by a new FTE hire. In this class students will be taught to recognize the importance of tools for reading the activity states of proteins, genes, cells and organisms. We will discuss the significance of programmable inputs in manipulating and engineering biology. By the end of the course, students will be able to design and model their own feedback controlled biological system. (New course, to be developed.)

**ME225EY Synthetic Biological Design, Control and Computing:** This course introduces the basics of design of synthetic biological systems, including the architecture of genetic networks, circuits, and pathways controlling engineered biological function, as well as single-cell microbial behavior, and microbe population dynamics. This course also will provide a gentle introduction to workflows in biomolecular engineering, genetic circuit design, genomic editing, as well as principles of experimental design. An overview of various engineered and natural biological functions is provided, including multi-stability, biological oscillations, stochastic effects in genetic circuits, robustness of circuit performance, and cellular capacity.


**D. Cell, tissue and device mechanics and engineering**

**MATRL270 Biomaterials and Biosurfaces:** The first part of this course will cover the fundamentals of natural and artificial biomaterials with an emphasis on surface and contact mechanics. The second part will focus on biological surfaces (biosurfaces) and delve into molecular-level structure and function. The third part will explore the dynamic interactions between biomaterials and surfaces with the body and designing for biocompatibility.

**ME225RS Engineering Biomaterials:** This lecture-based course will provide an overview of material structure-property relationships, processing, and characterization techniques for metals, polymers and ceramics. We will discuss the unique design constraints imposed by the human body and discuss strategies to enhance biocompatibility. Throughout the course, emphasis will be placed on applications of biomaterials engineering in medical devices.

**ME225BP Methods in Mechanobiology and Biofabrication:** Cell mechanobiology topics including cell structure, mechanical models, and chemo-mechanical signaling. Students will review and apply methods for controlling and analyzing the biomechanics of cells using traction force microscopy, AFM, micropatterning and cell stimulation, and practice and theory for the design and application of methods for quantitative cell mechanobiology. Course is comprised of weekly lecture and hands-on laboratory sessions.

**BIOEXXX Structure and Function of Biological Materials:** This course will introduce modeling tissues and cells using combination of biomechanics approaches, biomaterials models and transport models along with case studies of journal papers showcasing multi-scale and multi-mode analyses and experiments.

**BIOEXXX Cell and Tissue Engineering:** Cell and tissue engineering are rapidly growing fields within bioengineering. This course will examine fundamental biological processes and engineering tools essential to cell and tissue engineering both at the single-cell and the whole-organism levels. Topics
include stem cell engineering, cell–matrix and cell–scaffold interactions, cell–cell interactions and tissue morphogenesis, wound healing, and in vitro organogenesis. (New course, to be developed.)

**ME211 Pattern Formation and Self-Organization:** This is an introductory course to the processes of pattern formation and self-organization in natural systems (physical and biological systems) as well as in engineering. The goal of the course is to explain how ordered spatial structures appear in different systems. We will discuss the common aspects and the differences in the mechanisms that establish the patterns, and introduce various techniques used in different disciplines to study the formation of spatially extended structures.

**MEXXX Physics and Mechanics of Multicellular Systems:** The course will cover physical and mechanical aspects of multicellular systems, from 2D cell monolayers in culture and 3D cell aggregates to embryonic tissues. Cell mechanics in culture and in living tissues. Collective force generation and propagation. Measurement techniques to characterize mechanics in vitro. Tools to measure mechanics in developing embryos and living tissues. Fluid-to-solid (rigidity) transitions in multicellular systems. Spatiotemporal control of tissue mechanics. Mechanics of tumors. (New course, to be developed.)

**E. Electives**

**MATRL272 Mechanical Force and Biomaterials:** In this course, we will explore the field of single-molecule bio-physics, and in particular the role of mechanical force in biomolecular behavior. Mechanical forces are critical to a wide range of biological processes, and modern techniques allow the experimentalist to study those processes by directly measuring forces generated by biomolecules and/or perturbing the system with an applied force. The course will start off with an introduction to the experimental techniques used to apply force to single biomolecules (e.g., optical/magnetic traps, AFM, etc.), with a focus on quantitative calibration approaches. The remainder of the course will cover various aspects of the molecular biophysics of mechanical force, including the linear elasticity of biomolecules; DNA torsional mechanics and topology (twist, writhe); force-induced unfolding and unzipping transitions; and force-generation by motor proteins. Stochastic physical models of molecular behavior (e.g., Langevin, Kramers) will be a theme throughout. The course will draw on recent literature, culminating with student presentations of recently-published papers from the field.

**ECE594T Haptics:** Haptics refers to science and engineering related to the sense of touch. The course introduces human haptics, including anatomy, physiology, and perception for the tactile system. It presents aspects of the engineering of electronic technologies for addressing the sense of touch, and applications for the design of haptic systems for human-computer interaction, sensory substitution, virtual reality, and other creative areas. The class combines readings, hands-on activities, lectures, discussion, and projects.

**ECEXXX Introductory Bioelectronics:** This course plans to cover basic chemical and biochemical concepts, cells and their basic building blocks, basic biophysical concepts and methods, spectroscopic techniques, electrochemical principles and electrode reactions, biosensors, basic sensor instrumentation and electrochemical sensor interfaces, instrumentation for other sensor technologies, Microfluidics: basic physics and concepts and Microfluidics: dimensional analysis and scaling. (New course, to be developed.)

**PHYSXXX Soft Matter Physics:** The physics of soft condensed matter involves materials that are easily deformable by externally applied stresses, by electric or magnetic fields, or simply by fluctuations (of thermal or other origin). In this course we will use a physics-based approach to study the structure, assembly and dynamical properties of a variety of soft materials, such as simple and complex fluids, colloidal systems, liquid crystals, polymers, granular matter and gels, including biological examples. Topics covered will include elasticity, viscosity and viscoelasticity, capillarity and wetting, phases and phase diagrams of soft materials, entropy-driven phase transitions, Brownian motion and active matter. The level is appropriate for final year undergraduate students in physics. The course may also be of
MEXXX Bio-inspired design: In this course, students will learn how Nature can support the creative design process. Students will study evolutionary adaptation as a source for inspiration, extracting design principles to leverage the functionality, adaptability and robustness of biological systems. To advance student knowledge of biological strategies and facilitate quantitative analysis of the proposed solutions, the course focuses on biologically inspired design in fluids. Over the quarter, the students will learn how biological systems deal with fluids and the bio-inspired design process. The course includes lectures, case studies and hands-on design activities. Final projects will involve a team of students. Each team will select a biological system from our local zoo and define a design problem it solves. The students will then expand their search to learn about relevant biological systems. Students will (1) identify the design principles used by the biological system(s), (2) propose a bio-inspired design to achieve the identified function, and (3) produce a demo of the design principle and prepare a pamphlet describing their work to a general audience. (New course, to be developed.)

MCDBXXXX: Computational Methods in Behavior: The focus of this course is on the experimental and computational techniques and logic behind the design of experiments to quantify behavioral responses through automated tracking and closed-loop stimulations. (New course, to be developed.)

CS291I: Bionic Vision: This graduate course will introduce students to the multidisciplinary field of bionic vision, with an emphasis on both the computer science and neuroscience of the field. The course will give an overview of current bionic eye technology designed to restore vision to people living with incurable blindness. Students will be exposed to the neuroscience of the human visual system, key engineering concepts for designing a brain-computer interface, and computational principles underlying the encoding of a visual scene into an artificial stimulus that the brain can interpret. We will cover recent advances in theory and applications, and discuss outstanding challenges with existing devices. The course will conclude with a programming project (teams of ≤ 3, any language/environment ok) in lieu of a final exam, giving students an opportunity to gain hands-on experience of working on open research problems using methods and tools best suited to their scientific background. (New course, to be developed.)

F. Additional requirements

BIOE596 First Year Lab Rotations: First-year research rotations (1 unit per quarter), which serve to promote interdisciplinary training and collaboration, are a near universal component of bioengineering graduate programs. Students in the Biological Engineering Program will participate in four different mini-rotations in the Fall quarter (at least 3 of which are performed in Program faculty member labs, including those of the Affiliated Faculty) to identify projects for quarter-long research rotations during the Winter and Spring quarters of their first year.

BIOEXXX Bioethics and Responsible Conduct of Research: For graduate students and post docs, the UC Santa Barbara RCR training program will involve three components: 1) mandatory online RCR training, 2) an ethics seminar series, and 3) one-on-one mentoring from your faculty advisor. The online course is available through the CITI homepage at https://www.citiprogram.org/default.asp. The seminar series complements the online research ethics class, by providing a forum for discussion and further insights into ethical issues.

One elective option for translational experience. The following is a partial list, presented as examples.

ME128 Biomedical Devices: Introductory course addresses the challenges of biomedical device design, prototyping and testing, material considerations, regulatory requirements, design control, human factors and ethics.

MCDB294 Pharma Translation: Based on presentations by experts from the bioengineering industry. Presenters describe their companies’ technologies and developments, including biosensors, therapeutics,
tissue engineering, quantum dots and advanced instrumentation. Training and educational requirements for different career tracks are discussed.

**BIOEXXX: Industrial Internship Experience:** This internship will be designed to integrate academic studies through real-world practical applications in the workplace. By participating in the program, students can complete their degree while building their skills and resumes with relevant work experience. Student will be able to explore specific interests within their academic discipline and refine their post-graduation goals. (New course, to be developed.)
SECTION VI. RESOURCE REQUIREMENTS

A detailed budget is provided in Appendix H.

1. Faculty FTE

At its “kick-off” we anticipate that 12 current members of the UCSB faculty (Table 6) will transfer up to 50% of their FTE into the Program (see letters of commitment in Appendix E, and their professional qualifications in Appendix I). This Core Faculty will be responsible for developing, implementing and teaching the core curriculum and many of the focus area courses. Similar to both the graduate-only Materials Department at UCSB and to existing bioengineering programs in the UC system, we anticipate that the graduate student to faculty FTE ratio in the Program will be 6-12. Of note, this is higher than the average ratio in existing CoE departments, which, in turn, is 3 times higher than the campus average. That is, the program will start “lean” in terms of faculty FTE, but such is often the nature of new programs, particularly those that, like Biological Engineering, lack an undergraduate degree. To lessen the impact of this lean ratio the Program will also include 11 additional colleagues who will serve as Affiliated Faculty (Table 5). These faculty members, who will receive 0% appointments in the Program, will help us fulfill our obligation to teach the remaining focus area courses and will provide additional opportunities for graduate research (see their professional qualifications in Appendix I). To this end, all of the Affiliated Faculty already teach (or plan to teach) courses relevant to our proposed curriculum and, in consultation with their departmental Chairs, have already committed to: (1) opening enrollment of these courses to Program students and (2) teach these courses at least every 2 years for the initial years of the Program (see departmental and faculty member letters in appendices B and E). Taken together the Core and Affiliated Faculty provide 23 research groups in which Program students can conduct their thesis research.

We understand that the movement of up to 6 FTE from existing departments and Programs into Biological Engineering will reduce staffing in the former. This said, the home departments of many of the affected faculty members (e.g., Dey, Doyle, Pruitt, Stowers, Smith, and Mukherjee) attracted them to UCSB in part with a promise that they would be provided opportunities to help grow Bioengineering on our campus, in most cases with the explicit promise that the new hires would be allowed to transfer significant FTE into the Program when it is created (e.g., Dey, Doyle, Pruitt, Stowers). To facilitate this, there is explicit intention within CoE to restore impacted departments to their historical strengths through additional hiring as these transfers take place (see Dean Alferness’s letter of support in Appendix A). In parallel, we expect that (and have been informed that), in collaboration with this nascent Biological Engineering effort, a number of the existing CoE and MLPS departments intend to make new bioengineering-focused faculty appointments over the next few years, many of whom will presumably desire similarly joint appointments. We also note a strong synergy with emerging Data Science efforts on campus. Given that demand for courses in machine learning and bioinformatics already outstrips campus capacity, our desire is to jointly recruit faculty with CS and ECE who will contribute to the teaching and research demand in this arena. Specifically, our aim is to develop and implement an innovative graduate education model in our focus areas of Modeling and signal processing and Computational, Systems, and Synthetic Biology that train biological engineers able to work across disciplines and fluent in data analytics. For example, students choosing these focus areas will learn how to design and undertake research requiring integration of multi-modal, disparate data using machine learning and computational approaches to extract models and meaning from biological data. Overlaying this, we have also strategized at length (and will continue to do so) with the relevant faculty members and the Chairs of their current home departments to determine how to make this transition with the least possible negative impact on both the faculty and the current home department by, for example, carefully staging FTE transfers and teaching and departmental obligations. This is particularly true for those anticipated members of the Core
Faculty who will likely not yet be tenured when the Program is initiated (although all will be approaching the tenure decision at that time). Everyone involved recognizes that it would be unwise to place any unnecessary burdens on our untenured colleagues, and will work with them to ensure their continued success.

Given the curriculum we have developed, and the enthusiasm of the faculty members involved, these FTE “numbers” will be sufficient to launch the Program to a strong start. This said, the long-term health of the Program requires a larger faculty than the 6 FTE we anticipate at initiation. For example, depending on cognate departments for the teaching of so many focus area courses is tenuous in the long run, as the priorities and needs of the providing departments and faculty members—as well as those of the Program itself—will eventually shift. Given this we thus anticipate requesting 6 faculty appointments over the next 6 years as the Program expands its graduate educational offerings and prepares for the ultimate implantation of an undergraduate major in Biological Engineering. These additional Core Faculty members will provide long-term programmatic stability (e.g., buffer the Program against sabbaticals, administrative leaves, separations, etc.) and will ensure our ability to quickly build an undergraduate degree upon the ultimate formation of a department.

Finally, a note concerning 50:50 split FTEs, an idea that some on our campus consider “unwieldy” or otherwise problematic. We firmly believe that such splits are in the Program’s best interests (while simultaneously minimizing any potential negative impact on the current home departments) and that, likewise, they need not be at all problematic. Our rationale for such splits is that the anticipated Core Faculty already straddle two disciplines and a 50% split ensures that they can be counted on to provide one required course in each, plus an additional elective that will train students in particular concepts that by virtue of their interdisciplinarity, will serve both programs equally. Moreover, campus (and personal) experience suggests that such splits need not prove problematic; indeed, while rare in CoE, they are widespread on campus and have even occurred between the two colleges. The appointment of CBE Associate Director Plaxco, for example, has been split 50:50 (between Chemistry and Biochemistry and the BMSE Program) continuously since his hiring as an Assistant Professor more than 20 years ago. CBE Director Pruitt was 50:50 split between Mechanical Engineering and Bioengineering at her previous institution (which, like UCSB, also followed the quarter system) with no problems. Based on this experience we would argue that the number of potential problems (e.g., teaching assignments, which department or Program leads promotion cases, service load) is finite and easily defined, as are their solutions. Teaching assignments, for example, are easily negotiated on a good faith basis between the involved departments and/or Programs, and merit and promotion cases are traditionally led by the department or, in cases in which the split is between two departments, the lead department is decided again via negotiations that, in our experience, have never proven difficult.

2. Library acquisition
The UCSB library already supports the strong bioengineering research efforts on our campus (see support letter in Appendix A). No additional library expenditures are anticipated.

3. Computing costs
The CBE budget includes IT support for the CBE staff; we propose to transfer this to the Program to support the IT needs of its staff. The IT support costs will increase modestly due to increased FTE, as the IT service contract is based on a per FTE fee scale. This is increase is reflected in the budget (Appendix H).

4. Equipment
An initial investment in equipment is needed to nucleate the hands-on training in the core and focus courses of the curriculum. To realize the vision for Program training with laboratory and project
components, the Program will request one-time investment of $350K for a shared microscope to be housed in space committed by CoE for shared microscopy resources. Of note, several of the proposed Core Faculty members (Pruitt, Doyle, Smith, Streichan, Wilson) already volunteer their own laboratory space and equipment for experimental labs in their graduate courses, however microscopy is also a critical bottleneck for research projects and microscope time cannot easily be reprioritized for teaching. Thus, a microscope with teaching priority will anchor the hands-on training of our Program. Our faculty is eager to engage students in applied, project-based learning approaches. However, we have reservations about putting research equipment at risk under the projected increased student demand and enrollments expected with the Program. Thus, investment in a shared, user-friendly microscope is critically needed to provide state-of-the-art training to our students.

5. Space and other capital facilities
Due to the recently (Fall 2017) opened bioengineering building (Figure 2), no additional space will be required to create the proposed Program. While rapidly filling, the building retains sufficient unassigned laboratory space to house many of the proposed faculty hires and the proposed microscopy equipment, which would be housed in the shared microscopy facility in the building. Likewise, office space remains available to house the administrative staff of the proposed Program and, eventually, a department.

6. Other operating costs
The long-term success of the degree and Program will require sustained commitment from the campus to provide the resources necessary to teach the relevant courses and administer the degree. Two arguments speak to the feasibility of sustaining this commitment over the long term. First, as noted above, there is widespread enthusiasm regarding the continued growth of bioengineering on our campus and, with this, real and tangible interest by our administrators to fund the continued growth of bioengineering education and research as, for example, re-benchmarking funds flow to the campus. Specifically, the proposed Program will require new ladder faculty and the typical space and startup resources for these FTEs. The only other, on-going resources that will be required once the Program reaches steady state will be funds to purchase the equipment and supplies used in the hands-on laboratory courses. The associated costs, however, will be in line with those of many existing graduate laboratory courses in the sciences and engineering, and thus should be easily accommodated in the campus’s education budget.

a. Teaching assistants. We have discussed with the Deans of CoE and MLPS a request for university support for three 9-month 50% TA positions. Our motivation is two-fold. 1) These courses are expected to draw undergraduate enrollment from simultaneous efforts to expand bioengineering tracks for undergraduates, specifically in Chemical and Mechanical Engineering. Ultimately, this increased capacity for undergraduate teaching will have positive impact on departments in CoE and MLPS and have reach beyond just the new department. TA support will be critical to sustaining an open and hands-on curriculum with capacity for broader campus training, including undergraduates. 2) These TA positions will also provide an opportunity for Biological Engineering students to gain valuable teaching experience in their field, which will make them more competitive on the academic job market. This said, to ensure that our students are exposed to diverse teaching experiences, they will be required to complete two 50% TAships during their training, preferably in two different courses. To accomplish this, we expect (and will encourage) students to TA courses in the home departments of our Core and Affiliated Faculty. To this end, we note that Biological Engineering PhD students will be well-prepared, desirable candidates to fill TA positions in several of our campus’s departments that have been struggling to find sufficient numbers of qualified candidates, including both Molecular Cellular and Developmental Biology, Chemistry and Biochemistry, and several of the existing engineering departments.

b. Director, Associate Director, and Program Manager. To implement the new degree Program, CBE’s current Director, Associate Director, and Assistant Director will serve as the Program’s
leadership. These positions will be funded via the budget lines currently associated with the CBE administrators and staff and thus no additional funds will be required at this time.

c. **Administrative staff.** Staff lines to support a graduate student advisor and the Assistant Director/Business Officer will be transferred from existing staff lines in the Center for Bioengineering. The graduate student advisor will serve as the focus coordinator for the Bioengineering Graduate Emphasis and advisor to participating and prospective doctoral students of the Biological Engineering Program. The graduate student advisor will also be responsible for coordinating with the Program faculty in the assigning and hiring of students as teaching assistants.

In addition, to respond to the expected increase in enrollment, we request funds to support an Administrative Officer, who will help with finances, record keeping, oversight and development, distribution, maintenance of marketing materials to showcase the Program as well as CBE affiliated PhD programs and CBE BioE Graduate Emphasis to assist recruiting graduate students interested in bioengineering research. This staff person will also assist faculty members with background, collection of participant materials for proposals that will support the research and teaching mission for biological engineering and quantitative biology on campus, e.g., surveys of need, utilization tracking, management plans, and implementation of activities and events supporting funding with direct campus and trainee benefit

- Training grant proposals to NIH and NSF to gain sustainable funding for qualified PhD trainees and manage required activities,
- Center and large proposals with bioengineering education themes.
- Administrative activities related to coordinating the development, approval, and scheduling of new bioengineering courses.
- Instrumentation proposals to develop better quantitative biology and bioengineering capabilities for training

d. **Operating budget for the laboratory courses.** The recharge fees for core access to train students in cutting edge methods and tools, reagents, cell culture supplies, and other consumables necessary to sustain experimental components of core courses are estimated to cost $15k per year. These supplies will support laboratory experiences for all students enrolled in the core courses, mechanobiology, microscopy, and synthetic biology courses. We have discussed a request for this funding from the Dean of CoE, Dean of MLPS and the EVC (who currently support all CBE costs, including the Bioengineering Emphasis).
SECTION VII. GRADUATE STUDENT SUPPORT

Our expectation is that all of the Program’s graduate students will be funded for the entire duration of their graduate training. We will achieve this via a mixture of Program funding (block grant, development funds, etc.), TA positions, training grants, and, for at least three years, extramural research funding. With regard to the latter issue, bioengineering is a particularly well-funded area of academic research. For example, approximately a quarter of the $22M in annual funding our campus currently receives from the NIH was awarded to faculty members associated with the CBE (who represent far less than a quarter of UCSB’s biology-oriented faculty). Moreover, as noted above, UCSB’s share of federal funding from NIH is under-developed even relative to our sister campus that, like us, lack a medical school (Figure 3); the proposed Program will be well positioned to draw on this currently under-tapped funding resource.

The Program will also be well placed to obtain training grants as an element of its graduate student support. Specifically, the core Program faculty are committed (see letters of intent) to bringing to our campus NIH T32 training grant support, a flexible, highly attractive source of student funding that, with the notable exception of UCSB, are an integral part of bio-oriented graduate programs at UC campuses (Figure 6). These awards, which focus on specific research and training themes and are renewable (we note that with proper oversight and updating, some have run for 40+ years), can support 4 to 6 trainees. Thus, each T32 would fund, for example, 2 to 3 new students per year through both first-year research rotations and second year didactic training. The Core Faculty is also committed to applying for a one-time NSF research traineeship (NRT) grant that would help launch courses in the proposed curriculum around interdisciplinary training for bio-imaging, stem cell engineering, and complex data analysis (Pruitt submitted an FY20 NSF NRT proposal on 2/6/2020). To facilitate both efforts, CBE director Pruitt worked with the offices of Research Development and Graduate Division to create a workshop on “training grant best practices” and a grant writing “boot camp” for trainees in December 2019. The “boot camp” workshop for trainees also focused on applying for fellowships, such as the NIH F31 fellowship, a 3-year fellowship commonly awarded to 3rd year graduate students working on NIH-themed research. Together these workshops will provide background and benchmarking for successful proposals. The grant
writing boot camp in particular will demonstrate a track record of delivering bioengineering relevant professional development programs for trainees that are essential to be competitive for federally funded graduate training programs.

Additional graduate student support will come in the form of TA positions, which will also provide our students teaching experience, a core element of the proposed pedagogy. Some of these positions will be within the Program. Specifically, we will request campus support for three 9-month 50% TA positions, as described above.

Finally, Program faculty members are also actively working with campus development officers to raise funding for student fellowship support, with specific emphasis on funding to support the planned first-year research rotations. Such research rotations are a hallmark of top bioengineering (and biology and biochemistry) programs nationwide, and thus the ability to offer such rotations will be critical to attracting the best students.
SECTION VIII. GOVERNANCE

The Program in Biological Engineering, initially comprised of the Core and Affiliated Faculty described in Table 6 and Table 5, will be governed by the Program’s bylaws (see the proposed bylaws in appendix D).
SECTION IX. CHANGES IN SENATE REGULATIONS
No changes to UCSB senate regulations are required.
CIP Code: 14.4501
Appendix A: Administrator Letters of Support

The attached proposal was formulated after detailed, multi-year discussions with the campus administration, including the Chancellor, the EVC, the CoE, MLPS and Graduate Division Deans, and the Vice Chancellor of Research. Our understanding is that the reviewing agencies will directly solicit input from several of these administrators; we have thus limited the letters of support appended here to those from the Deans of CoE and MLPS and the Vice Chancellor of Research.
February 25, 2020

TO: Graduate Council

FROM: Rod Alferness, Dean
       College of Engineering

RE: Proposal for a Graduate Program in Biological Engineering and Ph.D. Degree

After reviewing the proposal outlining the new Graduate Program in Biological Engineering and the Ph.D. in Biological Engineering degree, and consulting with department chairs within the College of Engineering (CoE) who have written letters of support (see attachments), I would like to express my strong support for the establishment of this interdisciplinary graduate Biological Engineering Program.

A broadly interdisciplinary program in this emerging field at the intersection of biology and engineering builds upon and strongly leverages UCSB's existing strengths of highly cited, nationally and internationally recognized research in this area currently being conducted over colleges, departments, centers and research units. In particular, the proposal leverages our intercollege Center of BioEngineering founded in 2011 to foster cross-campus collaborative research and teaching at the intersection of engineering and biology. Since CBE’s founding, we in CoE have strategically recruited a number of faculty who are strong and deep in their core departmental themes and have, in addition, a strong interest and experience in exploring and addressing biological studies and questions. This is the thrust of “engineering for biology” that this Biological Engineering proposal cites. At the same time, in their collaborative endeavor with colleagues from campus scientists in MLPS, our CoE faculty have the opportunity to learn and leverage new skills and learnings in “engineering from biology”. Nature’s way of evolving, adapting and optimizing provides exciting models for engineers to understand, leverage and also to share with their CoE home department colleagues. That is the win-win situation for this interdisciplinary Biological Engineering proposal, a strong reason why CoE departments support it and are willing to allow partial FTE to be transferred to the new program to make it possible. I would suggest that the same value proposition applies for the faculty and departments in MLPS as well.

The proposed program will, for example, have strong links with all five CoE departments. For example, 8 of the 12 initial core faculty members with full or partial appointments in CoE (Pruitt, Campas, Dey, Doyle, O’Malley, Mukherjee, Smith,
Stowers) represent 3 CoE departments, with the other two both being represented by some of the 11 affiliated faculty. It also reaches across campus, with four of the initial core faculty having appointments in key MLPS departments.

As noted earlier, the CBE (Center for BioEngineering) provides a valuable foundation for the new program and degree to build upon. For example, the Bioengineering Emphasis administered by CBE is comprised of core Engineering courses and supported by elective courses from multiple CoE departments which will be cross-listed as electives in Biological Engineering. Chair Frederic Gibou of Mechanical Engineering fully supports the program’s establishment, noting that his department has already hired key faculty anticipated to move part of their FTE into the proposed new Program. Several courses in the proposed curriculum exist or are synergistic with a Systems Biology and Bioengineering track within Mechanical Engineering. Thus, they are committed to supporting requests by their faculty to split their FTE with Biological Engineering, to teach courses in the new curriculum, and to encouraging all faculty participation in supervising Biological Engineering students as appropriate.

Similarly, Chair Rachel Segalman of Chemical Engineering, notes strong synergies with her faculty and curriculum and supports the proposed joint appointments and cross-listing of courses. Chair Tevfik Bultan of Computer Science expresses his department’s support for the new graduate program, and he expects it to open up greater collaboration opportunities for his faculty, as well as to be a draw for prospective graduate students and joint faculty with interest in data science, bioinformatics and computational biology. Chair Michael Chabinyc of Materials notes synergies with faculty and research engaged in biomaterials from the molecular to the macroscale and expects a Biological Engineering Program will nucleate new collaboration opportunities and help recruit students with more applied biomaterials interests to UCSB. Chair Nadir Dagli of Electrical and Computer Engineering supports a new Program in Biological Engineering which will have synergies and collaboration opportunities for training students in bioimaging, bioelectronics and neural interfaces.

I firmly believe that UCSB’s superb record of achievement in research, rankings, awards, levels of intramural funding, and public recognition stems at least in part from its multitudes of joint appointments and the many cross-disciplinary collaborations that transcend individual departments and research units. The establishment of the Graduate Program in Biological Engineering can only enhance UCSB’s reputation as a world leader in the sciences and engineering, while positioning us as a catalyst in this established and growing field.
I support the proposed plan for graduate student support in the form of extramural funding, fellowships, TA positions, and a block grant funding request. I understand that the team is working on training grants and other support in parallel. I will work with Dean Wiltzius and the EVC to help provide the requested TA support for the first 6 years of the program to facilitate greater access to upper division undergraduates in emerging elective tracks. After this time, we expect a formalized undergraduate program will emerge and provide new sources of TA support. I will work with the CoE Departments, the EVC and Dean Wiltzius to prioritize allocation of FTE to support the hiring plan of 6 FTE over 6 years, including possible interdepartmental appointments and joint hires across CoE and MLPS. To facilitate hands-on training so critical to bioengineering training, I will also contribute to the purchase of the microscope proposed for hands-on student training that will be housed in space we have allocated for shared microscopy in the new Bioengineering building. I expect that this Biological Engineering Program will lay the groundwork for an undergraduate department and degree within the 6-year time frame noted.

I support the founding faculty FTE model of faculty members moving (for purposes of teaching percentage) partial FTE to the new program subject to the wishes of the faculty members and the approval of the home department faculty and the other Program faculty. Some may question the proposed recommendation of 50% rather than a majority or minority percentage appointment. While, it might be somewhat unusual, this 50/50 split is understandable given their context of proposing the program faculty will teach one course in their home department, one in the new program and one that is cross-listed between the home department and the program. In this case, with respect to the value to home department and the program, it would be a 50/50 split. It will be important also to have clear understanding of the service requirements to the home department and the Program. As noted in the proposal, from a permanent FTE accounting point of view, the FTE remains with the home department.

I thank you and reviewers in advance for giving this proposal their utmost consideration.

c: Beth Pruitt
   Kevin Plaxco
March 3, 2020

To: Divyakant Agrawal, Chair
   Graduate Council

Fr: Pierre Wiltzius
   Dean, Mathematical, Life and Physical Sciences

Re: Proposed Graduate Program in Biological Engineering

I am writing with my strong support for the proposed Graduate Program in Biological Engineering, a sub-discipline that sits squarely at the interface between engineering and the basic life sciences. The program will build upon current research and educational interests of faculty and students across both COE and MLPS, and will benefit the broader campus through increased access to curricular offerings, research opportunities and professional training. I am specifically supportive of the idea of hosting this Program jointly between COE and MLPS, as several MLPS faculty have been actively involved in the curriculum design and implementation plan for a training Program that would attract a distinct cadre of students and strongly advance quantitative biology research across a number of MLPS labs.

Despite the positive aspects that the new Graduate Program would bring to UCSB, there are a number of issues that I believe the campus must handle with delicacy and deliberation. These are as follows:

Faculty

As the core faculty have detailed in the proposal, the initial space required to establish the new program is already available in the Bioengineering building. The trickier part is establishing a large cohort of faculty. Of the 12 proposed core faculty, 4 are currently appointed in home departments and programs in MLPS. My understanding is that these faculty members intend to move up to 50% of their FTE into the nascent program, pending approval by the faculty in the departments.

As noted in the letters from the chairs of the relevant MLPS departments and programs (Physics, DCB, MCDB, BMSE), these departments are generally in favor of meeting the pedagogic interests and desires of their colleagues, but they are likewise cautious about managing the potential loss of FTE and any disruption in the career trajectories of the junior faculty involved (Wilson and Streichan). Regarding the former issue, my expectation is that the impact will be relatively small: MCDB and Physics would lose 5/6th and 1/6th FTE, respectively, with the anticipated 0.5 FTE transfers. Nonetheless, losing FTE from MLPS departments that are already highly-impacted by large undergraduate student numbers will have a negative impact on the already-high student/faculty ratios. While the proposal for FTE transfer promises
that these transfers will be staged to minimize impact on the junior faculty and their current departments, the impact must eventually be mitigated by backfill of these FTE, whether through joint hiring with the new Program or additional FTE.

**Biomolecular Science and Engineering**

The creation of the proposed Biological Engineering Program would represent both opportunities and risks for our existing BMSE Program. This graduate program was reviewed in 2015 and valued as a “tremendous asset to campus”. Yet, it was also pointed out by the PRP that the program could “benefit from a course correction” with greater “focus and consistent rigor”. In recognition of the nascent Bioengineering effort at the time, BMSE discussed in its response to the PRP report solutions to differentiate itself from a Bioengineering graduate program by possibly establishing a course sequence that would focus on Biomolecular Physics and Chemistry, Techniques in Biomolecular Analysis, and bioinformatics. This is but one example that would build on the existing strengths in BMSE while looking forward to synergies with the more engineering oriented graduate program in Bioengineering.

Given the importance of BMSE, and the campus’s desire to see it thrive, there are two issues that I believe bear careful consideration regarding the creation of the proposed Biological Engineering program. First, the creation of a graduate program that appears to have overlap may draw students away from BMSE, reducing its applicant pool. Given that the program currently attracts relatively small numbers, this could even lead to a “death spiral.” To avoid this, it is imperative that the BMSE program continue the “re-branding, refocusing” efforts detailed in its PRP response. I know that BMSE Director Rothman has called together a high-level “think tank” to work through what this might mean, and that at least five of the proposed Core and Affiliated Biological Engineering faculty are serving in this effort (Plaxco, Saleh, Dogic, Louis, and Streichan). In order to minimize any potential negative impact that Biological Engineering might have on our campus, it is imperative that the campus supports the proposed changes that come from this important effort. Second, the Biological Engineering Core Faculty propose to move 1 2/3 FTE from the BMSE program into the new Program. This is a large fraction of the 6 total FTE (spread over 32 faculty members) in BMSE, and thus could have a negative impact on that Program. This impact can, and should be, ameliorated. I note that all of these faculty intend to retain affiliation with BMSE and continue to cross-list their existing courses. Additionally, the BMSE program can rationalize its teaching expectations so as to better employ what FTE it has. As mentioned above, backfilling the FTE to program is also desirable, e.g., via FTE requests coming directly from BMSE. BMSE has not availed itself of this mechanism in the last dozen years and such requests would be timely. In addition to rebuilding FTE numbers, this would provide the program an opportunity to evolve in response to and build to its newly defined focus. Such searches might include, as mentioned in the BMSE letter, joint appointments with Biological Engineering in areas of common interest.

**Additional FTE**

I understand that Biological Engineering curricula are, traditionally, highly structured and course-heavy relative to most MLPS graduate programs, thus motivating the request for 6
additional FTE. This said, the staging and nature of these searches will require careful design, especially regarding potential joint appointments across CoE and existing MLPS departments and new Program. I look forward to working with the new program faculty and Dean Alferness to define the parameters of potential new FTE and how to integrate Biological Engineering searches with existing programs to the benefit of campus.

**Graduate Program vs. Department**

The explicit goal of the new Graduate Program is that it will be a stepping stone towards building a Bioengineering Department in a few years. While the question of how an interdepartmental graduate program will morph into a department will require careful consideration, it is understandably beyond the scope of standing up this much-needed new Program. Despite these concerns, I commit to working with Dean Alferness and the proposed Program leadership to determine the best mechanisms for how the fractional FTE of the faculty will be managed as a department proposal emerges, including how teaching in an eventual undergraduate program in bioengineering will evolve.

**Staffing**

The proposed program aspires to expand to 15 students per year. When it reaches those levels, the requested level of staff support for the Program may ultimately be justified. For a newly-minted program just starting out the request seems generous. Notably, both BMSE and IGPMS, while smaller than the proposed size of Biological Engineering, each employ only a 50% graduate advisor. That said, the existing staffing of CBE (including a 50% graduate advisor) is already more than fully-engaged with the activities of the interdisciplinary graduate emphasis in bioengineering which serves students from 13 departments and programs across CoE and MLPS. A Graduate Advisor position at 100% FTE to manage both the emphasis curriculum and the graduate program curriculum is reasonable, but any additional staff growth should be staged with the growth of the enrollments in the graduate emphasis and the Program.

**TAs**

The proposal also talks about the need for TAs. In MLPS these positions are provided based on well-justified need, and competition for them is intense as we do not have sufficient numbers of TA slots to support the current needs of our science departments. The campus currently allocates three TA quarters to CBE in support of the graduate emphasis courses. The emphasis includes two required courses and one elective, which are expected to see increased undergraduate enrollments as they are incorporated into upper division focus areas. If the Program would like TA allocations from MLPS it will have to justify these based on student numbers and well-documented need; it would be premature to assign these at this early stage.

In conclusion, I support the establishment of the new Graduate Program, but I hope we get as many of the possible issues figured out as possible.
Cc: Beth Pruitt
    Kevin Plaxco
    Andy Satomi
    Ed Blaschke
    Dorothy Satomi
January 29, 2020

Beth Pruitt
Bioengineering, Room 3108
University of California, Santa Barbara
Santa Barbara, CA 93106-5070

Dear Beth,

As Vice Chancellor for Research at UC Santa Barbara, I am writing to extend my strong support to your proposal to create a Biological Engineering Program at UCSB. Biological materials, processes and ideas are the substrates upon which the next technological revolution will be built. Given UCSB’s longstanding record of collaboration between engineering and the basic sciences, our campus is well positioned to be at the forefront of this revolution.

I believe that we have an opportunity to expand our campus’ research in biological engineering and the opportunity for increased funding in this area is also clear. While we have had some very significant new grants, we receive much less funding from biology-focused agencies than comparable institutions. In recognition of our growing strengths and opportunities in this area, the Office of Research has recently hired a Director of Research Development for Biological Engineering, Science and Technology to help keep faculty aware of funding opportunities and to help them prepare strong proposals for awards in support of their outstanding programs.

The Biological Engineering Program you propose is an exciting, logical and necessary next step to enhance research in this area on campus. I fully endorse the creation of this program.

Sincerely,

Joe Incandela
Vice Chancellor for Research

cc: Kevin Plaxco
February 10, 2020

Kevin Plaxco
Professor, Department of Chemistry and Biochemistry
Associate Director, Center for Bioengineering
University of California, Santa Barbara

Dear Prof. Plaxco,

I write in support of the Library’s support for the proposed PhD program in Biological Engineering.

The Library subscribes to the top 30 journals in biotechnology and the top 20 journals in biomedical engineering (as rated by Impact Factor in the 2018 Journal Citation Reports) through our systemwide contracts with Wiley, Springer/Nature, Taylor & Francis, IEEE and the Institute of Physics, as well as the growing number of open access journals in the field. The principal exceptions are the journals published by Elsevier (from 2019 to present) due to UC’s failure to come to agreement with Elsevier on a new contract last year. However, the University and the publisher are set to return to negotiations this spring and we are hopeful that the issue will be resolved; if it is not, the UCSB Library will subscribe individually to high-impact/high-use titles.

We also have access to a large number of current books in the field, including electronic books from Wiley, Springer, Taylor & Francis (CCR Press) and Knovel, and we are adequately funded to purchase any faculty requests outside of these resources. The University of California subscribes the most important indexing databases for researchers in bioengineering, including Compendex, SciFinder, BIOSIS Citation Index, Web of Science and Derwent Innovations Index. Our Research and Engagement librarians in the sciences and engineering disciplines are prepared to provide any library research support that the students and faculty in Biological Engineering may require.

Sincerely,

Kristin Antelman
University Librarian
Appendix B: Departmental Letters of Support

Draft written versions of this proposal were circulated to all potentially affected departments and programs, and, when requested, oral presentations at faculty meetings were provided. This included all five college of engineering departments (MechE, ChemE, Materials, CS, and ECE), seven Math, Physical and Life Sciences departments (MCDB, Chemistry and Biochemistry, Physics, EEMB, Math, PStat, Brain and Psychological Sciences), and two graduate Programs (BMSE and DYNS). Many provided critical input, and all save two (EEMB and Math) chose provide letters of support. The latter are collected in this appendix.
To: Beth Pruitt, Director, Center for Bioengineering  
From: Joel Rothman, Director, Biomolecular Science and Engineering Program  

Re: BMSE response to the Biological Engineering Ph.D. Program proposal  

Dear Beth,  

The Biomolecular Science and Engineering Program (BMSE) faculty has reviewed the proposal to create a Graduate Program in Biological Engineering, which has also been discussed at a BMSE faculty meeting. As you know, over much of UCSB’s history, the interdepartmental BMSE program in MLPS has offered a flexible curriculum supporting interdisciplinary doctoral training in both foundational and applied biomolecular sciences and engineering. Thus, there is substantial overlap in the training elements of the existing BMSE program and the proposed bioengineering program. As such, the proposed plan will have a very significant impact on the current BMSE program.

For more than four decades, BMSE (earlier called BMB) has trained a large number of PhD graduates. There have been recent exciting developments in the program, which has been undergoing substantial growth, with more PhD students and addition of new faculty contributing to many of the emerging interdisciplinary themes of the program. With many new faculty who have recently joined, or are soon to join BMSE, we are initiating an effort to revitalize the BMSE curriculum and training opportunities, poising the program to rise to a new level of prominence.

A successful collaborative partnership between a new bioengineering PhD program and an enhanced BMSE program has the potential to synergistically advance both fundamental and applied sciences in interdisciplinary biology at UCSB, provided that it is implemented in a way that ensures that the strength of both existing and new programs. BMSE stands to benefit from the proposed bioengineering PhD program in the following ways:

1. **Opportunities for joint interdisciplinary hiring.** The potential for future collaborative faculty hires between the proposed bioengineering program and BMSE in areas of common interest, including systems biology and biological modeling, would augment these areas to the great benefit of both programs. Given the overlaps between the proposed program and the broader scope of interdisciplinary quantitative biology, BMSE would enthusiastically look forward to working with the new bioengineering department to identify suitable joint hires between BMSE and the new bioengineering department.

2. **Expanded curricular opportunities.** BMSE would strongly support efforts to coordinate course offerings with the new bioengineering program. The proposed Biological Engineering curriculum promises to expand the number of courses available to BMSE graduate students. This curriculum also includes a number of graduate courses that are currently being taught by BMSE faculty. BMSE will be able to accommodate additional student numbers that might result from the new program and would enthusiastically welcome the participation of Biological Engineering students in these courses.
The program is also committed to working with the new bioengineering program to create joint courses that satisfy the needs of both cohorts of students.

3. **Potential training opportunities.** If BMSE faculty members who are interested in mentoring engineering-inclined doctoral students are permitted by the new bioengineering program to supervise students, it would enhance their research and training programs and the collaborative opportunities for BMSE students and faculty.

In addition to these clear benefits, there are major implications of the bioengineering plan in its current form that – on a simple objective basis -- could have tremendous negative impacts on BMSE if there are no mitigating actions.

There exist strong models for vibrant long-term partnerships between MLPS and CoE departments and programs at UCSB. Such partnerships create synergy between related fundamental (MLPS) and applied science (CoE) disciplines, for example between (1) Chemistry and Chemical Engineering/Materials, (2) Physics and Mechanical Engineering, and (3) Mathematics/Statistics and Computer Sciences, to name just a few. Gaining inspiration from these highly successful models of collaboration, there can be no doubt that maximum value would also be obtained by boosting the MLPS and CoE contributions to cross-disciplinary in basic and applied quantitative biology in parallel. Expanding fundamental physical/quantitative sciences through MLPS and applied sciences through CoE would elevate the programs to levels that are substantially greater than the sum of the two. However, this can happen only if both partners remain strong and are able to thrive over the long term.

Over its ~40 year history, the BMSE/BMB program has successfully trained a large number of PhD students, including many who hold leadership positions in academia and industry. These students have supported and advanced the research programs of many faculty in many departments across the university. As interdisciplinary science has evolved, so have the directions of BMSE, which is currently planning a roadmap for the future that brings together additional faculty and students from across the fundamental sciences in a highly interdisciplinary, flexible program that transcends departmental boundaries. As such, BMSE promises to remain a valuable collaborative partner for the new bioengineering initiative, provided that it is allowed a) to continue to thrive and grow with strong faculty membership and b) latitude for branding that is appropriate for its future vision in fundamental quantitative biomolecular and systems biology. However, if BMSE is eviscerated without mitigation, as described below, there would, in fact, be little partnership remaining to celebrate. Of prime importance, if the program were to terminated as a result of these losses, future students who do not see themselves as bioengineers, but who are driven toward the interfaces of fundamental biology and the other foundational sciences (physics, chemistry, mathematics, etc.) would no longer be drawn to pursuing doctoral studies at UCSB. The attendant intellectual cost of such an outcome to the university and to many present and future faculty whose programs benefit from the participation of such students is self-evident.

To create a synergistic whole that is much greater than the sum of the MLPS and CoE parts, the BMSE partner would need the following if it is to continue to flourish, thereby strengthening this promising partnership:

1. **Restoration of FTE in BMSE.** The proposal suggests moving most of the current major holders (0.5) of FTE out of BMSE, which is the overwhelming majority of FTE in the current program. This includes those faculty recently brought into BMSE through the MLPS Quantitative and Systems Biology (Qbio) initiative created over the past several year. It is self-evident that this would have a direct and devastating negative impact on the current momentum, growth, and revitalization of BMSE. This impact would be mitigated if, and only if, the lost FTE were rapidly and fully restored to the program through new hiring, including restoration of both junior and senior faculty. Without such immediate restoration and further growth, it can be objectively stated that the program would not continue to thrive and, in fact, would be gravely damaged. The restoration of faculty participation in the program would be absolutely essential to provide the training and teaching resources for revitalizing and
redesigning the BMSE curriculum and student recruitment activity. Continuing the current momentum and growth of the program would require not only this essential restoration of FTE, but further augmentation of additional faculty to the MLPS program.

2. **Rebranding of BMSE in its new incarnation focused on fundamental interdisciplinary biological sciences.** With the creation of a bioengineering PhD, it is logical for BMSE to relinquish the “engineering” brand, and the applied elements of “Biomolecular Science and Engineering.” This would provide an opportunity -- in fact, an imperative -- to rebrand the program with a heightened focus on foundational interdisciplinary biological science. This realignment of BMSE would span quantitative and systems biology, biomolecular science, biophysics/physical biology, neurosystems, biological dynamics, biological modeling, and other areas of fundamental interdisciplinary biological science that are advanced through the confluence of physics, chemistry, mathematics, statistics, computation, and biological science. This reorientation can succeed, however, only if the rebranded BMSE program can be defined through these basic science disciplines. The very broad branding/disciplines circumscribed by the current Biological Engineering proposal encompasses nearly all areas of both fundamental and applied science. Hence there remains very limited opportunity for BMSE to uniquely emphasize these areas of fundamental science in its new incarnation, thereby effectively preventing it from doing so.

There can be no question that UCSB, and a vigorous and transformed BMSE, can be greatly enhanced by a PhD program in bioengineering. The emergence of interdisciplinary quantitative biological sciences at both the fundamental and applied levels through two vigorous programs in MLPS and CoE, operating in partnership, will provide tremendous opportunities to advance both science and engineering at UCSB, provided that both can remain robust. There is much to be gained if a sustained BMSE and emergent bioengineering program work together as strong and equal partners in the enterprise of boosting training and research in fundamental and applied interdisciplinary biology, as has been so successfully demonstrated with many other collaborative partnerships at this university.

Sincerely,

Joel H. Rothman
Professor and Wilcox Family Chair in Biotechnology
Director, Biomolecular Science and Engineering
College of Engineering  
University of California, Santa Barbara  

October 16, 2019  

To: Beth Pruitt,  
Director, Center for Biological Engineering  

From: Rachel Segalman, Chair  
Department of Chemical Engineering  

Re: Chemical Engineering support for the interdisciplinary  
Biological Engineering Ph.D. Program proposal  

Dear Professor Pruitt,  

The Department of Chemical Engineering supports the proposal for a new Biological Engineering Ph.D. program. We look forward to promoting strong synergies with our faculty and the curriculum. We support Chemical Engineering faculty with strong bioengineering research programs, including Dey, O’Malley, and Mukherjee, to move part of their FTE at such time as the transition is best managed for each individual. The percentage of FTE to be moved by each individual will be subject to discussion with the faculty and a departmental vote (as per our departmental by-laws). Indeed, Chemical Engineering has strongly supported plans for this emergent program and the flexibility to move FTE was intended and committed to the more recent hires in this area. Similarly, we also support future discussions for proposed joint faculty searches, joint appointments, and cross-listing of relevant courses.  

There is likewise much interest from many of our faculty to participate in supervising Biological Engineering students. Similarly, students in the Biological Engineering Program will be welcome to enroll in any relevant Chemical Engineering courses.  

I wish you success with the proposal and program.
DATE: December 11, 2019

TO: Beth Pruitt, Director
    Center for Bioengineering

FROM: Steve Buratto, Chair
    Department of Chemistry and Biochemistry

RE: Chemistry and Biochemistry Support for the Interdisciplinary Biological Engineering Ph.D. Program Proposal

Dear Director Pruitt:

I have discussed the Biological Engineering Program proposal at some length with my colleague Kevin Plaxco, who is also CBE Associate Director. Based on these discussions I am writing to confirm the Department of Chemistry and Biochemistry’s (DCB’s) general support of the effort. The proposed interdepartmental graduate Program is clearly in the campus’s best interests, and likewise would have a significant, positive impact on DCB. A number of our current faculty, for example, work in areas related to bioengineering and, thus, will likely find the Program a valuable source of additional graduate students. Moreover, our future FTE plans envision augmentation of our faculty in the areas of biomolecular design, synthetic biology, and experimental systems biology; hires who will likely find the existence of a Biological Engineering Program on our campus an appealing draw. Finally, as the number of STEM majors on our campus inexorably grows, DCB has had trouble recruiting sufficient numbers of biology-trained TAs to support our upper division biochemistry courses; the students in your program could help fill these positions.

My understanding is that Professor Plaxco is the only member of DCB who currently anticipates moving FTE into the Program, and that this FTE will be that assigned to BMSE and not DCB. Thus, I do not anticipate that the creation of the program will have any negative impact on DCB.
Jan 20, 2020

Beth Pruitt, Director
Center for Bioengineering
UC Santa Barbara
Santa Barbara, CA 93106

RE: CS support for the interdisciplinary Biological Engineering Ph.D. Program proposal

Dear Professor Pruitt,

The Department of Computer Science has reviewed and supports the proposed creation of an interdisciplinary Biological Engineering Ph.D. program and, in due course, would be happy to explore joint hires between the program and the department. We believe that machine learning and bioinformatics are promising areas for growth for the Biological Engineering program and these areas would be especially suitable for potential joint hires. We also believe that the campus-wide efforts on Data Science and the proposed Biological Engineering program align well and would benefit from synergistic growth. Meanwhile, we understand that our colleague Prof. Linda Petzold anticipates a courtesy appointment in the Program; we of course support this.

Thanks for your efforts in preparing this well thought out proposal, and I wish you good success with the program.

Sincerely,

Tevfik Bultan
Professor and Chair
Department of Computer Science
University of California, Santa Barbara
January 13, 2020

To: Professor Beth Pruitt, Director, Center for BioEngineering

From: Jeff Moehlis, Chair of the Program in Dynamical Neuroscience (DYNS)

Re: Letter in support of the proposed Graduate Program in Biological Engineering

Dear Beth,

It is my pleasure to give my enthusiastic support for the proposed Ph.D. Program in Biological Engineering.

This is a particularly exciting cross-disciplinary endeavor which builds upon the campus’ existing strengths in this area, and it is evident from the proposal and my discussions with the Center for BioEngineering Associate Director that the new Program will establish UC Santa Barbara as a leader in the area of Biological Engineering. As for DYNS, the proposed Program brings together experts across multiple departments, a model which has served our Program well, and which is consistent with UC Santa Barbara's strategic plans for the future.

Moreover, the proposed Program is synergistic with the DYNS Interdepartmental Ph.D. Emphasis in Neuroengineering. Indeed, several of the courses proposed for the Biological Engineering curriculum would augment the campus’ existing offerings in this area. More broadly, DYNS has had a long-standing interest in neuroengineering, an area which would be strengthened if Biological Engineering makes this topic a major research focus, as appears to be the intention.

Thank you for the opportunity to comment on this proposal.

Sincerely,

Jeff Moehlis
Chair, Program in Dynamical Neuroscience
January 13, 2020

TO: Beth Pruitt, Director
Center for Bioengineering

FROM: Nadir Dagli, Chair
Electrical and Computer Engineering Department

RE: ECE Support for the interdisciplinary Biological Engineering Ph.D.
Program Proposal

Dear Professor Pruitt,

The Department of Electrical and Computer Engineering has reviewed the proposal for the interdisciplinary Biological Engineering Ph.D. Program. The creation of such an interdisciplinary program is timely, appropriate and needed. We support the proposed creation of a Biological Engineering Ph.D. program and, in due course, would be happy to explore the idea of joint hires between the program and our department. Meanwhile, we understand that our colleague Professor Spencer Smith anticipates moving 50% of his FTE to the new program and that Professor Theogaragan anticipates teaching a cross-listed course and will be offered a courtesy appointment in the Program. We encourage interested and qualified Biological Engineering graduate students to take relevant ECE graduate courses and hope that some of the new courses in your proposed curriculum may be of interest and open to our students. We understand the intention is to grow the proposed program into a department, and in the future, we would be happy to continue interacting in the areas described earlier.

I wish you good success with the program.
Jan. 10, 2020

Beth Pruitt, Director
Center for Bioengineering
UC Santa Barbara
Santa Barbara, CA 93106

RE: Interdisciplinary Biological Engineering Ph.D. Program proposal

Dear Professor Pruitt,

The Materials Department has reviewed and supports the proposed creation of an interdisciplinary Biological Engineering Ph.D. program. We understand the intention is to grow the proposed program into a department. Materials supports such efforts and is happy to explore future synergies.

We recognize that there are current Materials courses that could benefit Biological Engineering and we will examine the cross-listing of courses that benefit all students interested in bioengineering. We likewise foresee no problem in allowing Biological Engineering graduate students to take relevant Materials graduate courses and appreciate that, conversely, some of the new courses in your proposed curriculum may be of interest to our students.

We note that our colleagues Professor Omar Saleh and Assistant Professor Pitenis will be offered a courtesy appointment in the Program and we will support their decision.

I wish you success with the program and the Department appreciates your leadership in this effort.

Sincerely,

Prof. Michael Chabinyc
Department Chair
Materials Department
Beth Pruitt, Director  
Center for Bioengineering  
UC Santa Barbara  
Santa Barbara, CA 93106

January 22, 2020

RE: ME support for the interdisciplinary Biological Engineering Ph.D. Program proposal.

Dear Professor Pruitt,

The Department of Mechanical Engineering fully supports the establishment of a new interdisciplinary Biological Engineering Ph.D. program. Indeed, leveraging this exciting development has already helped our department hire multiple faculty with interests in mechanobiology. The latest of these faculty (Doyle, Stowers, and yourself) were recruited under the premise that they would move part of their FTE into the new Program when it is established.

Of note, we already have a Systems Biology and Bioengineering track within our graduate program, and the curriculum you have proposed will significantly augment the classroom training on offer for students in this track. Given this, we are committed to supporting requests by existing faculty to split their FTE with Biological Engineering and/or to teach joint courses in the new curriculum as part of their regular department teaching responsibilities. In the past year, we have also worked jointly with the Center for Bioengineering to establish a new undergraduate track in Systems Biology and Bioengineering which similarly benefits from continued synergies.

There is likewise much interest from many of our faculty to participate in supervising Biological Engineering students; the department is committed to providing these students with space and facilities in department labs as appropriate. Similarly, students in the Biological Engineering Program having the necessary perquisites will be welcome to enroll in any relevant Mechanical Engineering courses.
I wish you good success with the program.

Yours sincerely,

[Signature]

Professor and Chair of Mechanical Engineering

**Note:** The Department of Mechanical Engineering had a faculty meeting on 01-22-2020 to discuss the establishment of the interdisciplinary Biological Engineering Ph.D. program after reviewing the proposal under review. The 23 faculty members who attended the faculty meeting voted unanimously in favor.
MCDB supports the creation of the proposed interdisciplinary Biological Engineering Ph.D. Program. I believe many of my colleagues would be happy to participate in the program by accepting Biological Engineering Ph.D. students into their laboratories. I anticipate that the proposed Program will positively impact students in my department: many of the new courses proposed in your curriculum may be of interests to our students, which would provide them a breadth of training opportunities not currently available on our campus. MCDB will consider seriously any requests by our faculty to split their FTE with the Program, and any request to teach joint courses in the newly proposed curriculum.

Looking beyond the creation of the graduate program, I understand that your ultimate goal is the creation of a department and an associated undergraduate degree. This will impact MCDB positively by expanding upper division coursework in relevant areas of pedagogy. A potential negative, however, is the impact that any additional undergraduate enrollment in a biology-oriented field will have on our already impacted undergraduate courses. This, of course, is a solvable problem, and one that we look forward to working on with you and our campus leadership in due course.

From time to time MCDB may have open positions for teaching assistants that would be suitable for students in the Biological Engineering Ph. D. Program. However, we cannot guarantee that teaching assistant positions will be available. Indeed, in recent years we have had difficulty filling requests for TA positions from MCDB students and faculty.
20 November 2019

To: Beth Pruitt, Director  
   Center for Bioengineering

From: Claudio Campagnari, Chair,  
       Department of Physics

Re: Physics support for the interdisciplinary Biological Engineering Ph.D. Program proposal

Dear Prof. Pruitt,

Having spoken with Associate Director Plaxco, and reviewed the current draft of the Biological Engineering Graduate Program proposal, I confirm that the Department of Physics supports the creation of the proposed interdisciplinary Biological Engineering Ph.D. My colleagues and I will support this first and foremost because it is simply the right thing to do: biological engineering reflects an increasingly important area of research and pedagogy, and thus its absence on our campus reflects an important void that the proposed Program will fill. Beyond this rather general, campus-wide rational, I believe the Department of Physics would also specifically benefit from the proposed Program. First, as envisioned the Program would bring to our campus a cohort of talented graduate students that would support the research efforts of a number of our biophysics faculty. Second, as you know the Department of Physics is revamping and formalizing our undergraduate biophysics track; I anticipate that your willingness to open Biological Engineering courses to advanced undergraduates would provide a source of desirable electives for these students. Finally, given the rapidly increasing enrollment in our department and its similarly rapidly increasing service load, we have been struggling in recent years to find sufficient TAs for our undergraduate courses. Given the anticipated make up of your enrollment, I believe that many Biological Engineering graduate students would be suitable to fill this important role.

I also understand that several of my departmental colleagues anticipate being involved in the Program. Professor Sebastian Streichan, for example, is proposed as a “core member of the faculty,” meaning that he anticipates transferring half of his FTE into the Program. Given that Professor Streichan is currently 2/3 appointed to our department, this would mean the transferal of 1/6 of his FTE from Physics to the Program. Broadly speaking, I support this as the department always endeavors to meet the pedagogic interests and desires of our colleagues. This said, given that Professor Streichan will likely still be an Assistant Professor when the Program is initiated, the exact timing of the FTE transfer will likely require careful negotiation and scheduling. I also understand that you are in discussions with several other Physics faculty
members regarding 0% appointments that would require some coordination regarding the scheduling of biological-engineering-relevant courses taught in my department. I do not anticipate any significant issues associated with the required coordination.

Best of luck with your proposal.

Sincerely

Claudio Campagnari  
Professor and Chair  
Physics Department  
UC Santa Barbara
December 23, 2019

Beth Pruitt, Director
Center for Bioengineering
UC Santa Barbara
Santa Barbara, CA 93106

RE: Support for the interdisciplinary Biological Engineering Ph.D. Program proposal

Dear Director Pruitt,

CBE Associate Director Plaxco presented the Biological Engineering Program proposal to our Department at the December 2, 2019 faculty meeting, where it was well received. Given UCSB’s notable strengths at the intersection of the science and engineering, the idea of building in this area is compelling. And given our rapidly increasing understanding of biology and the vast potential of applying biological or biology-inspired solutions to human engineering challenges, it is likewise timely.

Having reviewed the draft proposal, I have no specific concerns regarding its impact on PSTAT. Several of the proposed new courses, such as Bioinformatics and Machine Learning in BioEng, would be of interest to our graduate students as electives. Indeed, while your currently planned curriculum does not involve any courses dedicated to (bio)Statistics, the idea of a future joint Biostats hire between PSTAT and the Program is well worth keeping in mind. Our PRP Development Plan from last year specifically mentioned joint hiring in the broad Biostat/QBio area, with the proposed Program being a natural partner.

Our Department supports the fact that the proposal maintains the campus’s existing graduate Bioengineering Emphasis, in which PSTAT has been involved since inception. Given the campus’s increasing focus on quantitative biology and bioengineering, we appreciate such opportunities to stay engaged with these broader -- and exciting -- trends.

Sincerely,

Mike Ludkovski
Professor and Chair, Department of Statistics and Applied Probability
November 22, 2019

TO:        Beth Pruitt
          Director, Center for Bioengineering

FROM:   Michael Miller
         Chair, Department of Psychological & Brain Sciences

RE:       PBS support for the interdisciplinary Biological Engineering Ph.D. Program proposal

I have read the draft proposal for the creation of an interdisciplinary Biological Engineering Ph.D. program and I am writing to express the Department of Psychological and Brain Sciences’ enthusiastic support. I anticipate that some of the courses in your neuroengineering track may be of significant interest to some of our graduate students and, likewise, I see no impediment to your students attending our graduate courses provided they have the appropriate prerequisites. Ultimately the Program could also serve as a source of graduate students for some of our faculty, particularly if the proposed neuroengineering track really takes off. I wish you the best of luck with this endeavor.
Appendix C: Bioengineering Institute of California Letters of Support

The Bioengineering Institute of California (BIC), an intra-UC Institute comprised of the leadership from the bioengineering departments of all nine of our sister UC Campuses, has provided Professors Pruitt and Plaxco a venue in which to present this proposed Program to the wider UC community and to receive its feedback regarding both “best practices” and potential pitfalls to avoid. As detailed in the letters presented here from the founding and current directors of the Institute, the bioengineering programs of the other UC campuses are aware of and supportive of the Program we are proposing.
December 28, 2019

Beth Pruitt, Director, Center for Bioengineering
UC Santa Barbara
Santa Barbara, CA 93106

RE: Support for the UCSB Biological Engineering Ph.D. Graduate Program proposal

Dear Professor Pruitt,

I strongly support the establishment of a new interdisciplinary Biological Engineering Ph.D. graduate program at UC Santa Barbara. I was the founding director of the Bioengineering Institute of California (BIC) and founding Chair of the Department of Bioengineering at UC San Diego, the first bioengineering graduate program in the UC system. As such, I can attest to the need for expanded training opportunities for bioengineering in the UC system. As you have detailed in your proposal, the demand for student training in bioengineering far outstrips the capacity of the current programs offered across the UC system.

UCSB is well positioned to contribute a successful training program to the system. Your campus has been an active participant in the BIC Steering Committee and the BIC Annual UC System-Wide Bioengineering Symposium. UCSB hosted extremely successfully the 2nd and 12th Annual Symposium, and will host the 22nd Annual Symposium in 2021. Through these joint efforts, BIC facilitates cross-fertilization in research and training among campuses in the interdisciplinary field of bioengineering. Its mission is to synergize the strengths and expertise on different campuses, and foster the cooperation among them to create a coherent and cohesive network of shared information, resources, dissemination and public engagement. The three National Laboratories (Lawrence Berkeley, Lawrence Livermore, and Los Alamos) are also partners of BIC.

It is greatly appreciated by all bioengineering programs in the UC System that the UCSB Center for Bioengineering, with your excellent leadership, took initiative in 2018 to unify the efforts of the UC campuses by organizing the first joint UC Systemwide University Reception at the annual meeting of the Biomedical Engineering Society (BMES). This exciting event has served to promote bioengineering training at BMES, and it was a strong step in promoting your new program and existing training opportunities side by side with the sister UC campuses. The BMES Meeting is the key conference in the field of bioengineering for promoting bioengineering training, research and opportunities to prospective students, faculty and our
colleagues. The reception led by you was a resounding success that was repeated and improved upon in 2019, and BIC now plans to continue this as an annual tradition to promote synergy across our programs and raise our collective profile and reputation for excellence. UCSB, under your leadership, has made all these important events possible.

It is wonderful that the proposed Ph.D. Program at UC Santa Barbara will leverage your campus’s exceptionally collaborative environment and notably strong relationships between engineering and the sciences. It will be unique among UC campuses in that it will focus on Biological Engineering, thus uniting the application of biological principles, materials and systems to create tangible, economically viable solutions for technological challenges, with the application of the tools and concepts of engineering to advance our understanding of biology.

In summary, UC Santa Barbara already has the right ingredients for success, including outstanding faculty, superb research, excellent facilities and an impressive culture of collaborative, interdisciplinary research and training at the intersection of biology and engineering. I am pleased to see this effort coalesce into a formal training program and I would like to offer my strongest support to make your program a great success.

Best regards,

Sincerely yours,

Shu Chien, M.D., Ph.D.
University Professor of Bioengineering and Medicine
Y.C. Fung Professor of Bioengineering
Director, Institute of Engineering in Medicine
Beth Pruitt Ph.D.
Director, Center for Bioengineering
UC Santa Barbara
Santa Barbara, CA 93106

January 13, 2020

RE: Support for the UCSB Biological Engineering Ph.D. Graduate Program proposal

Dear Professor Pruitt,

It is a pleasure for me to write this letter in strong support of the establishment of a Graduate Program in Biological Engineering effective Fall 2021. In my role as the Director of the Bioengineering Institute of California (BIC) and as a Founding Professor of the Department of Biomedical Engineering at UC Davis, I offer my full support for your proposal for a new interdisciplinary Biological Engineering Ph.D. program at UC Santa Barbara and eventual department and undergraduate programs. As we have observed throughout California in the past decade, student demand for bioengineering training and industry demand for graduates in this field exceed the combined capacity of graduate programs across the UC system. UCSB is the last campus to formalize a degree program and department in bioengineering but already has the ingredients for success in reputation and makeup of the faculty in this area.

I currently direct BIC which is a multi-campus research unit that is empowered by UCOP to facilitate cross-fertilization in research and training among campuses in the interdisciplinary field of bioengineering. In fact, a primary objective is to foster improvement and expansion of the discipline throughout the ten UC campuses. UCSB has been an active participant in the BIC mission to synergize the strengths and expertise on different campuses, and to foster cooperation to create a coherent and cohesive network of shared information, resources, dissemination and public engagement. For example, UCSB has always sent students and faculty to participate in the BIC Annual UC SystemWide Bioengineering Symposium, last hosted by UCSB in 2011 and hosted next by UCSB in 2021 with the 22nd Annual Symposium.

I also applaud the leadership of UCSB and the Center for Bioengineering for taking the lead in 2018 to organize our campuses in the inaugural and now annual joint UC Systemwide University Reception at the annual meeting of the Biomedical Engineering Society. The work of yourself and the Assistant Director Elizabeth Jensen has greatly enhanced the presence and prestige of UC Systemwide bioengineering at this key conference. I envision by establishing a bone fide Ph.D. program in Biological Engineering, it will go a long way in promoting UCSB’s excellence in bioengineering training, research and opportunities for prospective students, faculty and our peers.

I am pleased to see this proposal for formal training program in the field of bioengineering emerge at UCSB and offer my strongest endorsement and support of the BIC to help launch and make your program a success.

Sincerely,

Scott I Simon, Ph.D.
Professor
Department of Biomedical Engineering. Director of the Bioengineering institute of California
Appendix D: Proposed bylaws for the Biological Engineering Program
Proposed by-laws for the interdepartmental Biological Engineering Program

I. Organization:

A. Major policy decisions will be decided by faculty vote as described in sections III, V, VI, and VII. These include curriculum and degree requirements, appointments and re-appointments, merits and promotions, and bylaw changes.

B. The Director is responsible for the overall administration of the Program, including organization of academic personnel cases, faculty appointments, and oversight of the budget, supervision of the staff, committee assignments, teaching assignments, and development.

C. The Director calls and chairs faculty and Executive Committee (defined below) meetings, prepares and distributes the agenda for such meetings, and the summary of actions taken at such meetings. The Director serves also as a conduit between the Program’s faculty and committees, between the Program and the Chairs of the other Departments of faculty members jointly affiliated with the Program, and between the Program and the University Administration.

D. The Associate Director is responsible Program administrative functions as determined in consultation with the Director. He or she acts in place of the Director in the latter’s absence. If the position of Director becomes vacant, the Associate Director serves as director until a replacement Director is selected.

E. The Graduate Advisor, who is appointed by the Director, chairs the Graduate Committee, selects the Program faculty member who will chair each student’s pre-candidacy thesis committee (oral exam committee), and has the sole authority to approve curricular replacements based on course equivalence.

F. The Diversity Officer, who is appointed by the Director, is responsible for ensuring diversity “best practices” are employed during student recruitment, admissions, and training, and in faculty recruitment.

G. The “Core Faculty” is comprised of those faculty senate members with non-zero FTE appointments in the Program.

H. The “Associated Faculty” is comprised of those faculty senate members with 0% appointments in the Program.

II. The Appointment of Program officers:

A. The Program Director is appointed by the COE and MLPS Deans following consultation with the Program faculty and according to University procedures. The Director will be appointed with the expectation that the normal period of service will be a three (3) year renewable term, with re-appointment on a year-by-year basis at the pleasure of the Deans.

B. The Associate Director is selected by the Deans in consultation with the Program Director and faculty.

III. Faculty meetings:

A. Faculty meetings are called, as the need arises, by the Director. However, a faculty meeting
will also be held if requested in writing by at least two Program faculty members.

B. Faculty meetings will be used to keep the Program faculty informed regarding matters of interest via reports from the Director and Associate Director, committees, and the faculty at large, and to provide a forum for dealing with action items. Agendas for meetings will be distributed in advance of the meetings. Any member of the Program faculty may propose agenda items and such items by submitting such items to the Director. These will be placed on the agenda of an upcoming meeting as expeditiously as possible.

C. Faculty meetings are chaired by the Director, or, if absent, the Associate Director, or, if absent, a faculty member designated by the Director. The procedure for meetings is governed by Robert’s Rules of Order.

D. All Program faculty members are eligible to vote in all votes except those for personnel cases. Rules for voting on personnel cases are set out in Section V.

E. The presence (in person or via teleconference) of a quorum of 50% plus 1 of the Core Faculty is required to take a vote at a faculty meeting (by a show of hands or, as noted below, by secret ballot) after a motion and a second has been made. Faculty members who are unable to attend a meeting may record their votes with the Director. If a quorum is not present, voting may be conducted online, with voting open for a period of at least 3 business days. Votes are decided by a simple majority of the votes cast. Votes must be by secret ballot for appointments and merit and promotion cases. Other votes may be by secret ballot at the request of any member of the Program faculty.

IV. Program Committees:

A. The Program has a number of standing committees including, but not restricted to, the Executive Committee, the Curriculum and Student Affairs Committee, the Graduate Admissions Committee, and the Merits and Promotions Committee. The Director is empowered to, as he or she deems necessary, create ad hoc committees focused on any other topic for which there is not a standing committee.

B. Committee leadership and members are appointed by the Director for a term of one year.

F. When requested by the Director, the Executive Committee provides advice concerning the overall development of the policies and procedures of the Program, formulating long-range plans, and any other aspects of Program management deemed appropriate. Executive Committee meetings are called, as the need arises, by the Director.

C. The Curriculum and Student Affairs Committee is composed of at least four Program faculty members. The staff Assistant Director and the staff Graduate Student Advisor serve as ad hoc members. The Committee is charged to act on behalf of the Program faculty, implementing policies in all areas of the graduate degree, including financial aid, laboratory rotations, and examinations.

D. The Graduate Admissions Committee is charged to govern student admission to the Program, student recruitment, and marketing.

E. The Merits and Promotions committee comprised of at least three Program faculty members will select ad hoc committees as needed in response to faculty and staff personnel cases.
V. Program Appointments:

A. A decision to recommend the hiring of a new faculty member into the Program is made by a vote of all senate faculty members (at any level of appointment) in the Program. A hiring decision requires discussion at a faculty meeting including a quorum of 50% + 1 of the Core Faculty. Voting on hiring is by anonymous, on-line ballot commencing after this faculty meeting and continuing for at least 3 business days. In hiring decisions unanimity is not required, but it is desirable, and thus the Director will endeavor to facilitate consensus.

B. Appointments to the Program faculty may be fractional. The minimum, non-zero fractional appointment is 33%. Faculty members who contribute less intensively to the Biological Engineering curriculum but whose affiliation has obvious mutual benefit for Program students may be considered for a 0% appointment to the Program faculty. Such 0% appointments are for a 5-year renewable term, subject to review and subsequent reappointment via a majority vote of the Core Faculty.

VI. Advancements and Promotions of Ladder Faculty and Teaching Professors:

A. All senate faculty at any level of appointment in the Program are allowed to view and participate in the faculty meeting discussion of any merit and promotion case for which they are not in conflict. No faculty member may view or participate in the faculty meeting discussion of his or her own case or any other case for which a significant conflict of interest exists.

B. Personnel cases will be reviewed by an ad hoc committee of at least two members, selected by the Merits and Promotions committee and drawn from the Program faculty. To facilitate communication, the identity of the ad hoc committee Chair will be known to the candidate. The remainder of the committee will remain anonymous. For career review cases the ad hoc committee will identify external letter writers if the Program is leading the case. Upon studying the case record and, in consultation with the Director, the committee is tasked with making a recommendation and presenting the case and this recommendation at a faculty meeting for discussion prior to the vote of the eligible faculty. For career review cases the faculty meeting must achieve a quorum of at least 50% plus 1 of the Core Faculty.

C. Eligibility to vote on merit and promotion cases is limited to faculty senate members having non-zero appointments in the Program and having tenure, security of employment, or successful completion of a Formal Appraisal. Eligibility to vote on all other merit or promotion cases is limited to faculty senate members having non-zero appointments in the Program. No faculty member may vote on his or her own case or on any other case for which a significant conflict of interest exists.

D. Faculty members who wish to have their personnel cases reconsidered under section I-10 of the Red Binder must submit to the Director a written rebuttal to the reviewing agencies’ decision in which the faculty member presents a “compelling argument for reversal of the original decision.” The Director will consult the faculty. A formal reconsideration case will be prepared by the Director only if the outcome of a secret ballot vote is stronger than or equal to the outcome for the original case.
Appendix E: Letters of commitment from the core and associated faculty

Our intention is that the core faculty will consist of 12 current UCSB faculty members, each of whom have agreed to transfer 50% of their FTE into the Program upon its launch. Letters of commitment from these faculty members are presented in the first half of this appendix, in alphabetical order. In addition, the Program will also include 9 faculty members with 0% “courtesy” appointments. Letters of commitment from these faculty members are presented in alphabetical order in the second half of this appendix.
RE: Confirmation of support for the interdisciplinary Biological Engineering Ph.D. Program proposal

Dear Beth,

I am very excited to participate as a core faculty member in the Biological Engineering Ph.D. program. This is an excellent opportunity for UCSB to develop the important interface between biology, chemistry, engineering, and physics, and I will help in any way I can to make this initiative successful. I will recruit and mentor graduate students from the Biological Engineering Ph.D. program (and provide them office space and support within my lab). Also, I commit to regular teaching in the courses detailed in the proposal for the required curriculum. I intend to transfer at least 50% FTE to the Program, and up to 2/3 FTE if this will help the program in the future. This means that I will teach at least one course for the program every year and two courses to its benefit every other year. Currently, my teaching is aligned such that I will teach a cross-listed course which supports requirements for the graduate program in my home department and also the proposed program, as well as one other course in the proposed curriculum.

Cordially,

Otger Campàs
Beth Pruitt, Director  
Center for Bioengineering  
UC Santa Barbara  
Santa Barbara, CA 93106

Dear Beth,

I am writing to confirm my participation as a core faculty member in the Biological Engineering Ph.D. program. As we have discussed, I am excited about the opportunity for UCSB to develop a cutting edge program at the interface between biology, chemistry, engineering, and physics. I will recruit and mentor graduate students (and provide them office space and support within my lab).

In addition, I commit to regular teaching in the courses detailed in the proposal for the required curriculum. I intend to transfer 50% FTE to the Program. I will teach at least one course for the program every year and two courses to its benefit every other year. Currently, my teaching is aligned such that I will teach a cross-listed course, which supports requirements for the graduate program in my home department and also the proposed program, as well as one other course in the proposed curriculum. I am very excited to participate in the new program.

Sincerely,

[Signature]
Dennis O. Clegg  
Professor and Co-Director
RE: Confirmation of support for the interdisciplinary Biological Engineering Ph.D. Program proposal

Dear Beth,

I am very excited to participate as a core faculty member in the Biological Engineering Ph.D. program that several of us have worked hard over the last few years to develop. This is an excellent opportunity for UCSB to build a new curriculum with a concomitant degree at the interface of engineering, biology, chemistry, and physics.

I intend to recruit and mentor graduate students from the new Program (and provide them office space and support within my lab). Also, I commit to regular teaching in the courses detailed in the proposal for the required curriculum. I intend to transfer 50% FTE to the Program, pending approval by my home department. Every year I will teach one course for the program and another course by cross-listing it with Chemical Engineering. Currently, my teaching is aligned such that I will teach the cross-listed course which supports requirements for my home department and also the proposed program.

Sincerely,

Siddharth Dey, Ph.D.
Assistant Professor
Chemical Engineering, Center for Bioengineering and Neuroscience Research Institute
University of California, Santa Barbara
January 14, 2020

Prof. Beth Pruitt, Director
Center for Bioengineering
University of California, Santa Barbara
Santa Barbara, CA 93106

RE: Confirmation of support for the interdisciplinary Biological Engineering Ph.D. Program proposal

Dear Director Pruitt,

I am very excited to participate as a core faculty member in the Biological Engineering Ph.D. program that several of us have worked hard to develop. This is an excellent opportunity for UCSB to build new curriculum with a concomitant degree at the important interface of engineering biology, chemistry, and physics. I intend to recruit and mentor graduate students from the Biological Engineering Ph.D. program, including providing them office space and support within my lab. Also, I commit to regular teaching in core courses such as Cell and Tissue Engineering (a new course included in the program proposal) and ENGR 220A: Molecular Bioengineering, which also supports requirements for the graduate program in my home department, or other courses as needed to train biological engineering graduate students.

After the Program is launched, and in discussion with the Mechanical Engineering Department to help ensure a smooth transition for all parties, I anticipate transferring up to 50% FTE to the Program. This level of FTE will help us to establish a core of existing faculty who are committed to program development, which will be supplemented by new FTE as part of the proposal plan. My colleagues in the Department of Mechanical Engineering (which currently holds 100% of my FTE) are aware and supportive of this plan.

Best Regards,

Adele Doyle
Assistant Professor
Mechanical Engineering
RE: Confirmation of support for the interdisciplinary Biological Engineering Ph.D. Program proposal

Dear Professors Pruitt and Plaxco,

I am very excited to participate as a core faculty member in the Biological Engineering Ph.D. program that several of us have been brainstorming and shaping for the past several years. This is a terrific opportunity for UCSB to lead at the interface between biology, chemistry, engineering, and physics. I commit to recruit and mentor graduate students associated with the new Program (and provide them office space and support within my lab). Also, I commit to regular teaching in the courses detailed in the proposal for the required curriculum. I intend to transfer up to 50% of my FTE to the Program, i.e., I will teach at least one course for the program every year and two courses to its benefit every other year. Currently, my teaching is aligned such that I will teach a cross-listed course, which supports requirements for the graduate program in my home department and also the proposed program.

Sincerely,

Arnab Mukherjee, Ph.D.

Arnab Mukherjee, Ph.D.
Assistant Professor
Department of Chemical Engineering
(ph): (805) 893-5137
(email): arnabm@engineering.ucsb.edu
January 22, 2020

University of California, Santa Barbara
Department of Chemical Engineering
Engineering II, Rm. 3349
Santa Barbara, California 93106-5080
RE: Confirmation of support for the interdisciplinary Biological Engineering Ph.D. Program proposal

Dear Beth,

I am very excited to participate as a core faculty member in the Biological Engineering Ph.D. program that several of us have been brainstorming and shaping for the past several years. This is an excellent opportunity for UCSB to lead at the interface between biology, chemistry, engineering, and physics.

I commit to recruit and mentor graduate students associated with the new Program (and provide them office space and support within my lab). Also, I commit to regular teaching in the courses detailed in the proposal for the required curriculum. I intend to transfer up to 50% of my FTE to the Program, i.e., I will teach at least one course for the program every year and one-two courses to its benefit every other year via cross-listing courses with Chemical Engineering. Currently, my teaching is aligned such that I will teach a cross-listed course, which supports requirements for the graduate program in my home department and also the proposed program.

Sincerely,

Michelle O’Malley
Associate Professor
Department of Chemical Engineering
Dr. Beth Pruitt  
Director, Center for Bioengineering  
University of California, Santa Barbara  
Santa Barbara, CA 93106

Dear Beth,

As you know, I have been formally involved in every effort to build Bioengineering on our campus; I truly believe it is the right thing for UCSB to do. As you also know, I, too believe that a core of dedicated faculty with large-fractional FTE in the Program will be key to its success. Given this, I am delighted to confirm my interest in transferring 50% of my academic appointment from the BMSE Program to the Bioengineering Program when the latter is approved. In preparation, I have discussed this matter at length with the BMSE director, Joel Rothman, and my departmental chair, Steve Buratto. As all of the graduate courses I teach are in the former, my anticipation is that every other year following my FET transfer I will continue to teach one graduate course of interest to both BMSE and BioE, and that every year after the transfer I will teach one course for the Chemistry curriculum, and one of the core courses in BioE.

Of course, a graduate curriculum consists of significantly more than just classroom teaching. To this end, I am happy to host rotation students and, ultimately, program students in my laboratory, and to serve on graduate committees and in any other role required of me in the administration of the Program. I am eager to continue my role in shaping this program, and look forward to further conversations to refine the curriculum development plan to benefit our students.

Best wishes,

Kevin W. Plaxco
From: Beth L. Pruitt  
Date: January 21, 2020  
Re: Biological Engineering Program Proposal

I respectfully submit the attached Proposal for a Ph.D. Program in Biological Engineering on behalf of its proposed core faculty. Since arriving on campus in 2018, I have been formally involved in the effort to define and design a degree granting program at UC Santa Barbara. I moved here because our campus has the ingredients and the trajectory to build and deliver a unique, world class program that will shine amongst the bioengineering programs in existence at our sister campuses and across the country. I started my faculty career in Mechanical Engineering at Stanford in 2003 just as Bioengineering was formalized as a graduate program and new department. I watched how that top ranked program evolved over 15 years to become ranked 3rd in the country and I eventually transitioned my primary appointment to Bioengineering. I believe that UC Santa Barbara has made a series of excellent, strategic, and collegial decisions and investments, esp. in the new building and rising star junior faculty, that positions us well to immediately deliver a new Ph.D. program. With modest further investment in resources, we will be well positioned to proceed next to build a department and undergraduate program.

I am delighted to confirm my interest in transferring 50% of my academic appointment from the BMSE Program and Mechanical Engineering Department to the Biological Engineering Program when the latter is approved. In preparation, I have discussed this plan with the BMSE director, Joel Rothman, and my departmental chair, Frederic Gibou. I further confirm my interest in serving as Director of the proposed Program and navigating the path to a department and undergraduate program.

I commit to developing and teaching in the new curriculum, to host rotation students and, ultimately, to mentor and support Program students in my laboratory, and to serve on graduate committees. I look forward to doing my part to make this Program a success for campus, my colleagues, and especially our students.

Sincerely,

Beth L. Pruitt, Ph.D.
Beth Pruitt, Director  
Center for Bioengineering  
UC Santa Barbara  
Santa Barbara, CA 93106  

RE: Confirmation of support for the interdisciplinary Biological Engineering Ph.D. Program proposal  

Dear Beth,

I am excited to participate as a core faculty member in the Biological Engineering Ph.D. Program that we have been developing. This is an excellent opportunity for UCSB to develop the important interfaces between biology, chemistry, engineering, and physics.

I will recruit and mentor graduate students, and this commitment of course includes providing office space and support within my lab.

Also, I commit to regular teaching in the courses detailed in the proposal for the required curriculum. I intend to transfer 50% of my FTE to the Program. This means that I will teach at least one course for the program every year and two courses to its benefit every other year. Currently, my teaching is aligned such that I will teach a cross-listed course which supports requirements for both the graduate program in my home department (Electrical & Computer Engineering, ECE) and the proposed program, as well as one other course in the proposed curriculum.

My current teaching focuses on two courses on optics & imaging and a course on neuroengineering approaches to measuring and manipulating neural activity. These are all new courses I have developed, and the material is relevant to the Biological Engineering Ph.D. Program.

Sincerely,

Spencer LaVere Smith, Ph.D.  
Associate Professor  
Department of Electrical & Computer Engineering
Dear Dr. Pruitt,

I am very excited to participate as a core faculty member in the Biological Engineering Ph.D. program that several of us have worked hard to develop. This is an excellent opportunity for UCSB to build new curriculum with a concomitant degree at the important interface of engineering biology, chemistry, and physics. I intend to recruit and mentor graduate students, including the provision of office space and support within my lab. Also, I commit to regular teaching in the core course ENGR 220B Cell and Tissue Bioengineering, and at least every other year, to teach ME 125/225-RS Engineering Biomaterials, which also supports requirements for the graduate program in Mechanical Engineering, my home department.

After the Program is launched, I intend to transfer up to 50% FTE to the Program. This level of FTE will help us to establish a core of existing faculty who are committed to program development, which will be supplemented by new FTE as part of the proposal plan. My colleagues in the Mechanical Engineering department (which currently holds 100% of my FTE) are aware and supportive of this plan.

Sincerely,

Ryan Stowers  
Assistant Professor  
Department of Mechanical Engineering  
University of California, Santa Barbara
Dear Beth,

I am writing in support of the proposed interdisciplinary Biological Engineering Ph.D. program that we developed together. As you know, I view this as a great opportunity for UCSB to further develop the budding efforts in quantitative biology, at the interface of physical sciences, biology, and engineering. I am excited about the idea of regularly teaching courses described in the proposal, as required for the curriculum. In fact, I’m already teaching some of these classes as part of my teaching responsibilities for BMSE and the physics department. Therefore, I am happy to consider moving 50% of my academic appointment to the Bioengineering Program (1/3 BMSE, and 1/6 physics) when it is approved. I further look forward to recruit and mentor graduate students from the program. This shall include office space as well as support from my lab.

Sincerely

Sebastian J Streichan
RE: Confirmation of support for the interdisciplinary Biological Engineering Ph.D. Program proposal

I am enthusiastic to participate as a core faculty member in the Biological Engineering Ph.D. program. This is an exciting opportunity for UCSB to leverage its highly collaborative environment to develop a program that trains students to apply engineering principles to an enormous range of biological systems. I will recruit, mentor and provide lab space to graduate students, if they choose to join my lab. As the program develops, I commit to regular teaching in the courses detailed in the proposal or to develop new courses, which I will teach for the required curriculum. Ultimately, I intend to transfer 50% FTE to the Program, i.e., half of my teaching load will be dedicated to supporting the bioengineering program. I am currently developing a cross-listed course, which supports requirements for the graduate program in my home department and also the proposed program.

Sincerely,

Dr. Maxwell Wilson
Assistant Professor of Quantitative and Systems Biology
Department of Molecular, Cellular and, Developmental Biology
Dear Beth,

This letter confirms my interest in participating as affiliated faculty in the new interdisciplinary Biological Engineering Ph.D. program. I commit to supervising and supporting Biological Engineering Ph.D. students who join my lab, and to providing these students with space and facilities in my laboratory. I have discussed this with my department chair, and I have departmental support to continue teaching CS-291I Bionic Vision (part of the Biological Engineering Graduate Program) and to provide seats to Biological Engineering students.

Best wishes,

Michael Beyeler
Assistant Professor
Department of Computer Science
Department of Psychological & Brain Sciences
Interdepartmental Graduate Program in Dynamical Neuroscience
University of California, Santa Barbara
bionicvisionlab.org
Dr. Beth Pruitt  
Director, Center for Bioengineering  
University of California, Santa Barbara  
Santa Barbara, CA 93106  

Dear Beth,  

This letter confirms my interest in participating as affiliated faculty in the new interdisciplinary Biological Engineering Ph.D. program. I commit to supervising and supporting Biological Engineering Ph.D. students who join my lab, and to providing these students with space and facilities in my laboratory. I have discussed this with my department chair, and I have departmental support to provide seats to Biological Engineering students. I am also willing to include any future course that I teach in Soft Matter and Biological Physics in the Bioengineering curriculum.  

Best wishes,  

Zvonimir Dogic  
Professor of Physics
January, 27th 2020

Dear Beth,

This letter confirms my interest in participating as affiliated faculty in the new interdisciplinary Biological Engineering Ph.D. program. I commit to supervising and supporting Biological Engineering Ph.D. students who join my lab, and to providing these students with space and facilities in my laboratory. I have discussed this with my department chair, and I have departmental support to continue teaching Bio-inspired design in fluids (part of the Biological Engineering Graduate Program) and to provide seats to Biological Engineering students.

Best wishes,

Dr. Emilie Dressaire  
University of California, Santa Barbara
February 24, 2020

Dr. Beth Pruitt
Director, Center for Bioengineering
University of California, Santa Barbara
Santa Barbara, CA 93106

Dear Beth,

This letter confirms my strong interest in participating as affiliated faculty in the new interdisciplinary Biological Engineering Ph.D. program. I commit to supervising and supporting Biological Engineering Ph.D. students who join my lab, and to providing these students with space and facilities in my laboratory. I have discussed this with my department chair (Prof. Frederick Dahlquist). I have received departmental support to teach a new class entitled “Computational methods, instrumentation & logic to quantify behavior” (to become included in the Biological Engineering Graduate Program) and to provide seats to Biological Engineering students.

Best wishes,

Matthieu Louis, PhD

Assistant Professor
Department of Molecular, Cellular and Developmental Biology
University of California Santa Barbara
February 5, 2020

Dr. Beth Pruitt  
Director, Center for Bioengineering  
University of California, Santa Barbara  
Santa Barbara, CA 93106  

Dear Beth,

This letter confirms my interest in participating as affiliated faculty in the new interdisciplinary Biological Engineering Ph.D. program. I commit to supervising and mentoring Biological Engineering Ph.D. students who join my group. I have discussed this with my department chair, and I have departmental support to provide seats to Biological Engineering students in relevant physics courses I may teach. I am also willing to include any future course that I may develop and teach in Soft Matter and Biological Physics in the Bioengineering curriculum.

Sincerely,

M. Cristina Marchetti  
Professor of Physics  
UC Santa Barbara
Dear Beth,

This letter confirms my interest in participating as affiliated faculty in the new interdisciplinary Biological Engineering Ph.D. program. I commit to supervising and supporting Biological Engineering Ph.D. students who join my lab, and to providing these students with space and facilities in my laboratory. I have discussed this with my Department Chair, and I have departmental support to continue teaching ME210B (part of the Biological Engineering Graduate Program) and to provide seats to Biological Engineering students.

Best wishes,

Linda Petzold
Professor, Department of Mechanical Engineering and
Department of Computer Science
Dear Beth,

This letter confirms my interest in participating as affiliated faculty in the new interdisciplinary Biological Engineering Ph.D. program. I commit to supervising and supporting Biological Engineering Ph.D. students who join my lab, and to providing these students with space and facilities in my laboratory. I have discussed this with my department chair, and I have departmental support to continue teaching MTRL 270 (part of the Biological Engineering Graduate Program) and to provide seats to Biological Engineering students.

Best wishes,

Angela Pitenis
Dear Beth,

This letter confirms my interest in participating as affiliated faculty in the new interdisciplinary Biological Engineering Ph.D. program. I commit to supervising and supporting Biological Engineering Ph.D. students who join my lab, and to providing these students with space and facilities in my laboratory. I have discussed this with the heads of the two academic programs with which I am affiliated (the Materials Department and Biomolecular Science and Engineering Program), and I have departmental support to include my course MAT/BMSE 272 as part of the Biological Engineering Graduate Program. I commit to providing seats in that course to Biological Engineering students. I further commit to teaching this course every other year over the first 5 years of the existence of the Biological Engineering Graduate Program.

Best wishes,

Omar Saleh
January 23, 2020
Dear Beth,

This letter confirms my interest in participating as affiliated faculty in the new interdisciplinary Biological Engineering Ph.D. program. I commit to supervising and supporting Biological Engineering Ph.D. students who join my lab, and to providing these students with space and facilities in my laboratory. I have discussed this with my department chair, and I have departmental support to develop a new course “Introduction to Bioelectronics” offered to both students in the ECE department and also to Biological Engineering students. This course will also be part of set of courses available to the Biological Engineering Graduate Program.

Best wishes,

Luke S. Theogarajan
Professor
Center for Bioengineering
Department of Electrical and Computer Engineering,
3010 BioEngineering Bldg.,
University of California, Santa Barbara
Phone: 805-893-3985
Email: lusthe@ucsb.edu
To: Dr. Beth Pruitt  
Director, Center for Bioengineering  
University of California, Santa Barbara  
Santa Barbara, CA 93106

Re: Letter of interest and support for the Biological Engineering Ph.D. Program

Dear Beth,

I am writing to confirm my enthusiastic support for the new interdisciplinary Biological Engineering Ph.D. program, and my interest in participating as affiliated faculty. I commit to supervising and supporting Biological Engineering Ph.D. students who join my lab, and to providing these students with space and facilities in my laboratory. I have discussed this with my department chair, and I have departmental support to continue teaching the graduate course in haptics that I offer annually (which would contribute to the Biological Engineering Graduate Program), and to provide seats to Biological Engineering students.

I am currently Associate Professor at the University of California Santa Barbara, with appointments in the Department of Electrical and Computer Engineering (33%) and Media Arts and Technology Program (67%). My laboratory is undertaking research on haptics – technologies addressing the human sense of touch –, on soft electronics, and soft and bioinspired robotics. I received the PhD in Electrical and Computer Engineering from McGill University, and spent several years in industrial research and development. I have published more than 70 scholarly works. I received a National Science Foundation CAREER Award in 2018, a Hellman Faculty Fellowship in 2017, and a Google Faculty Research Award in 2016. My research has been supported by multiple grants from the National Science Foundation. I currently serve as General Co-Chair of the 2020 IEEE Haptics Symposium, the primary academic meeting in the field of haptic science and engineering within North America.
I very much look forward to the new interdisciplinary Biological Engineering Ph.D. program and to the many benefits that I am certain it will provide to our campus and to the broader research communities it will address.

Sincerely,
Yon Visell, Ph.D.

Associate Professor
University of California, Santa Barbara
Department of Electrical and Computer Engineering
Media Arts and Technology Graduate Program
Department of Mechanical Engineering (By Courtesy)
California NanoSystems Institute
Dr. Beth Pruitt  
Director, Center for Bioengineering  
University of California, Santa Barbara  
Santa Barbara, CA 93106

Dear Beth,

This letter confirms my strong, enthusiastic interest in participating as affiliated faculty in the new interdisciplinary Biological Engineering Ph.D. program! I commit to supervising and supporting Biological Engineering Ph.D. students who join my research group and to providing these students with research space and facilities in my laboratory. I have discussed this with my department chair, and I have departmental support to continue teaching ME125/225EY *Biological Circuit Design and Computing* and ME125/225EY Applied Machine Learning (as part of the Mechanical Engineering electives and Biological Engineering Graduate Program) and to provide seats to Biological Engineering students.

Best wishes,

[Signature]

Enoch Yeung

Assistant Professor  
Department of Mechanical Engineering  
Biomolecular Science and Engineering Program  
Center for Control, Dynamical Systems, and Computation
Appendix F: Existing and proposed core and focus area courses

Collected in this appendix are the syllabi and catalog descriptions of the existing and proposed courses that will comprise the Program curriculum.
Biomolecular and Biochemical Methods
Instructors — Arnab Mukherjee, Kevin Plaxco

Course Description:
The goal of the course is to generate in our students and understanding of the logic behind the key tools used to characterize biomolecules and biosystems. Both the mechanisms by which these techniques work, and the rational for why each would be employed (strengths, weaknesses, potential pitfalls).

Learning Objectives:
- **Biochemical Methods: students bring own computers**
  - Spectroscopies
    - **Theory**: UV-Vis, RAMAN, Small Angle Scattering, Dynamic Light Scattering, Fourier-transform infrared spectroscopy
    - **Computer lab** – Practice data interpretation
  - Separation Part 1: Electrophoresis, Approaches in biomolecule separation
    - **Theory**: DNA, RNA, protein gels; separation methods: isoelectric focusing (gel); charge (pH); specific binding; organic compounds, mass (centrifuged density gradients)
    - **Computer lab** – Practice data interpretation
  - Separation Part 2: Chromatography/Separation
    - **Theory**: gas chromatography, liquid chromatography, optional mass spectrometry?
    - **Computer lab** – Practice experimental design
  - NMR with XRay crystallography, electron microscopy
    - **Theory**
    - **Computer lab** – Practice experimental design
- **Biomolecular Methods [Lab class; flipped classroom + weekly lab] – expose to BNL and cores**
  - PCR – do in practice
    - **Intro theory lecture**
    - **Lab class** – PCR [computer option: bioinformatics lab/primer design, etc.]
  - Gene cloning with cell transfection -- do in practice
    - **Cloning and transfection theory lecture**
    - **Lab class** – Transfection [option: experimental design; interpreting results, troubleshooting]
  - Gene Editing – theory only, time to finish experiments from week 1 and 2
    - **Gene editing theory lecture**
    - **Journal club, free lab time**
  - Immunostaining with flow cytometry -- do in practice but with microscopy?
    - **Immunostaining and flow cytometry (light) theory lecture**
    - **Lab class** - staining
  - In Situ Hybridization with fluorescence microscopy – do in practice but with IF?
    - **Theory lecture**
    - **Lab class** - microscopy follow up to theory lecture
  - Next-Gen Sequencing – theory only, time to finish experiments from week 3 and 4
    - **Theory lecture**
    - **Journal club OR course material review**
Suggested Learning Objectives (10 weeks):

- **[Knowledge]**: Be able to define common methods for manipulating and measuring biomolecules, especially nucleic acids, amino acids, polymers, and chemical compounds (weak on carbohydrates and lipids?).
- **[Comprehension]**: Be able to explain the physical principles underlying these methods, and link them together in a concept map.
- **[Application]**: Be able to demonstrate knowledge of biochemical and biomolecular methods by practicing simple methods in teaching lab settings.
- **[Synthesis]**: Be able to formulate an experiment from start to finish using one or a few covered methods, with a clear stated purpose and all essential controls, with discussion of how they will interpret the data.
- **[Analysis & Evaluation]**: Be able to appraise experiments the strengths and weaknesses of the experimental design (from published journal articles, or proposed by peers) used for acquiring the results.

**Lecture and Lab**


**Prerequisites:** General chemistry, general biology
Quantitative Experiments
Instructors — Max Wilson, Sid Dey

Course Description:
Build course around the experiment/analysis workflow and case studies of:

- **Design an Experiment:** Experimental design considerations and *a priori* assumptions: topics include Probability (concept of power), sampling noise, DOE, Mutual information and dimensional reduction, selection of appropriate controls and null hypothesis
- **Analyze Data and Test Hypotheses:** Statistics (distributions, parametric (\(\mu, \sigma, \chi, s, t\)-test, ANOVA and when to use non-parametric analyses. Review some papers with good and bad experimental or statistical design.
- **Build a Model** - ODE + PDE, linearization, dimensional analysis

Learning Objectives:

- **Probability and Statistics**
  ○ Presenting and summarizing data
  ○ Basics of probability theory
  ○ Random variables & probability distributions
  ○ Random sampling, estimation of parameters
  ○ Confidence intervals
  ○ Testing of hypothesis
  ○ Goodness of fit
  ○ Nonparametric tests
  ○ Regression and correlation analysis

- **Modeling Biological Systems**
  ○ Ordinary differential equations – analytical and numerical
  ○ Laplace transforms and Fourier analysis
  ○ Partial differential equations – analytical and numerical
  ○ Basics of Linear Algebra and Eigenvalues, Eigenvectors etc.

Lecture Only

Textbooks: None

Prerequisites: Required course for incoming graduate students in the BioE Program

Notes:
1. Some of these topics can be paired with programming assignments
2. As part of assignments, students can be asked to pick papers that use some of these techniques and show that they can reproduce the results in the paper
Great Experiments
Instructors — Beth Pruitt, Sebastien Streichan

Course Description: This course introduces students to seminal experiments that introduced pioneering biological engineering methods and experimental analysis. Students will learn the principles of sound experimental design to test a hypothesis, become familiar with techniques using bacterial and stem cell model systems, as well as imaging and analysis methods.

Learning objectives for great experiments to prepare students for experimental work in the lab:

- Consulting and project planning with rotation PIs, groups of 2-4 students identify a bioE project with appropriate quantification plans and control experiments.
- How to design experiments to advance in the project.
- Determine core parameters such as sample size required for a successful experiment.
- Read and repeat successful experiments.
- Determine core parameters such as sample size required for a successful experiment.
- Hands on mastery of Microscopy, Statistics, Cloning, cell culture.

Examples of great experiments to be repeated by the students in preparation for their rotation project

- Genetic mutations in absence of selection (Luria & Delbrück), [http://www.genetics.org/content/genetics/28/6/491.full.pdf]
  - **Goal:** Quantitative understanding of statistics of genetic mutations.
    - Grow bacterial cultures, streak out on different agar plates, and expose to selection pressure such as lambda phage.
  - Hypothesis from Luria: mutations appear after exposure and in response to a selection criterion.
  - Therefore expected number of survivors are poisson distributed.
  - Students will measure size of various colonies, and establish the distribution, to test the null hypothesis.
  - **Deliverable:** learn to decide whether to accept or reject the null hypothesis.
    - **Techniques:** Simple culture methods, microscopy, and quantitative analysis tools.
    - **Requirements:** Basic culture environment and microscopy, computer access.

- Stochastic gene expression in individual cells: [http://www.elowitz.caltech.edu/publications/Noise.pdf]
  - **Goal:** Quantitative understanding of how to model noise in gene expression.
  - Clone bacteria for expressing two fluorescent constructs.
  - Test role of intrinsic vs extrinsic noise in gene expression by defined environmental conditions
  - **Deliverable:** Identify limits of small copy number on defined gene expression levels.
    - **Techniques:** Single cell fluorescence microscopy, time lapse live imaging, Single cell segmentation and tracking
    - **Statistical analysis of obtained time traces**
Requirements: Basic culture environment. High resolution microscopy, computer access.

- **Tissue patterning** ([https://www.nature.com/articles/nmeth.3016](https://www.nature.com/articles/nmeth.3016))
  - **Goal**: Quantitative understanding of pattern formation at the tissue level.
  - Targeted differentiation of stem cells into germ layer precursors on micro patterned islands.
  - Identify how geometric confinement results in spatially ordered patterns of differentiating pluripotent stem cells.
  - BMP4 triggers differentiation, in a colony size dependent fashion
  - **Deliverable**: Identify role of colony geometry of colony in controlling differentiation patterns in a quantitative manner.

Techniques: antibody staining, sterile technique, stem cell colony maintenance, micro patterning, high resolution microscopy

Requirements: Stem cell culture environment and high resolution microscopy, computer access.

Outline:

**Week 1-5:**
- What made the example experiments a great success?
- Repeat example experiments and evaluate reproducibility
- Conceive novel group projects appropriate to rotation labs, and formulate initial ideas.
- Define experimental procedures.

**Week 6-8**: Carry out project

**Week 9-10**: Analysis and wrap up

Format: Lecture and Lab

Textbooks: Barker “At the Bench” and primary literature

Prerequisites: Quantitative Experiments; Biomolecular and Biochemical Methods
Course description

This course is the first part of a two-quarter course on Physics of Living Matter (with the second part to be taught in the Winter quarter by Shraiman). We will analyze physical phenomena involved at different scales in the process of building an embryo. You may think that animal (or plant) development is a problem of Biology. But Morphogenesis - generation of form - holds equally exciting questions for Physics. For example, addressing the question 'How does DNA encode shape?' involves ideas and concepts from Physics at all levels. The first part will focus on molecular and single cell-scale phenomena. The second part will address behavior of cell collectives, and mechanisms and mechanics of pattern and shape formation.

Tentative course outline

<table>
<thead>
<tr>
<th>Topic</th>
<th>Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macromolecules</td>
<td>Sequence and structure</td>
</tr>
<tr>
<td></td>
<td>Basics of polymer physics</td>
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<td></td>
<td>DNA elasticity</td>
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<td></td>
<td>Optical tweezing</td>
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<td></td>
<td>Protein folding problem</td>
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<tr>
<td>Structures inside the cell</td>
<td>Nucleus and Organelles</td>
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<td>Super-resolution microscopy</td>
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<td></td>
<td>Basic Physics of Membranes</td>
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<td>Phase separation and membraneless organelles</td>
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<tr>
<td>Molecular machines</td>
<td>Molecular motors and polymerases</td>
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<td>Single molecule measurements</td>
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<td>Kinetic proofreading</td>
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<td></td>
<td>Ion pump</td>
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<td></td>
<td>Flagella motor and ATP polymerase</td>
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<tr>
<td>Single cell behavior</td>
<td>Cell motility</td>
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<tr>
<td></td>
<td>Traction force microscopy</td>
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<tr>
<td></td>
<td>Cell cycle</td>
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<tr>
<td></td>
<td>Stochasticity of gene expression</td>
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</tbody>
</table>
BMSE 219: Basic Microscopy for Quantitative Biology
Instructor — Sebastian Streichan

Course Description:
Fluorescence live imaging is a powerful tool to study dynamics of living matter. This course provides an overview on geometric & Fourier optics, bright field microscopy, and fluorescence & absorption spectroscopy. Practicing these concepts students will construct a light-sheet microscope.

Learning Objectives:
- Fluorescence; Basic components of the microscope for manipulating light
- Diffraction and interference for image formation
- Complex microscope systems, e.g. EPI, Confocal, 2 photon, Light sheet.

Contents: Focus is on practical application
- What is light and Color?
  a. History and summary of what comes
- Geometric optics:
  a. Reflection/ refraction / fermat / Huygens principle
  b. Imaging by optical systems
  c. Refraction at spherical surface
  d. Thin lens approximation
  e. Cylindrical lenses
  f. Stops / Entrance and Exit pupil
- Diffraction and Fourier Optics
  a. Point spread function
  b. Numerical Aperture
  c. Spatial resolution
  d. Chromatic aberration?
- Optical systems and Fluorescence microscopy techniques
  a. Human Eye
  b. Molecular basis of Fluorescence Microscopy
  c. Filters, dichroic etc.
  d. Köhler/EPI Illumination
  e. FRAP
  f. FRET
  g. TIRF
  h. FLIM
- Advanced Fluorescence microscopes
  a. Confocal Line scanning
  b. Spinning Disc
  c. Two photon
  d. Super Resolution Techniques
- Light sheet microscopy
  a. Basic concept
  b. Digital imaging
  c. Image synthesis
  d. Deconvolution

Lecture and Lab
Optics & Imaging A

2 lectures per week (17 lectures total), in-class midterm, final, in-class reviews for both exams
Tuesdays & Thursdays, 2:00-3:50 p.m.
Phelps Hall 1431

Instructor: Spencer LaVere Smith
sll@ucsb.edu
sllslab.org
3101 BioE

Office hours: Tuesdays 12:30-1:00pm and by appointment

Winter 2019

Schedule

Jan 8: Lecture 1
Jan 10: Lecture 2
Jan 15: Lecture 3
Jan 17: Lecture 4
Jan 22: Lecture 5
Jan 24: Lecture 6
Jan 29: Lecture 7
Jan 31: Lecture 8

Feb 5: Lecture 9
Feb 7: Review
Feb 12: Midterm
Feb 14: Lecture 10
Feb 19: Lecture 11
Feb 21: Lecture 12
Feb 26: Lecture 13
Feb 28: Lecture 14

Mar 5: No class – Lecture 15 online
Mar 7: Lecture 16
Mar 12: Lecture 17
Mar 14: Review

Mar 18-22: Final exam (to be scheduled)
Lectures

Introduction
1. Course introduction, basic observations
   a. Goals for the course
   b. Course outline/syllabus
   c. Grading plan
   d. Why imaging?
   e. Modern applications of imaging

2. Historical background
   a. BCE
   b. CE

Light as a ray
3. Geometric optics
   a. Reflection
   b. Refraction
4. More geometric optics
   a. Basic mirrors
   b. Basic lenses

Light as a wave
5. E&M
   a. Interference
   b. Diffraction
   c. Mie scattering
   d. Rayleigh scattering

Light as a particle
6. Quantum mechanics
   a. Light-matter interactions
      i. Fluorescence
      ii. Phosphorescence
      iii. Multiphoton excitation
   b. Imaging system design: Photon budgets

Lenses
7. Lens technology
   a. Glass
      i. Types
      ii. Characteristics
      iii. Manufacturing
   b. Lens specifications
      i. Spherical lenses
      ii. Aspherical lenses
      iii. Defect characterization
   c. Aberrations
      i. Types of aberrations
      ii. Metrology
      iii. Wavefront detection
      iv. Adaptive optics (deformable mirrors)

Optical components
8. Non-lens optical components
   a. Polarization optics
      i. Splitting S&P
      ii. Changing polarization
      iii. Pockels Cells
   b. Interference optics
      i. Filters
      ii. Dichroic mirrors
   c. Directing light
      i. Shutters
      ii. Scan engines
         1. Galvanometer mirrors
         2. Resonant scanners
         3. Acousto-optical deflectors
         4. Electro tunable lenses

Detecting light
9. Detectors
   a. Cameras
      i. CCDs
      ii. CMOS
      iii. sCMOS
      iv. Photography and cinema market sensors
   b. Photodetectors
      i. Photomultiplier tubes
      ii. Hybrid photodetectors
      iii. Photodiodes

MIDTERM EXAM

Imaging principles
10. Properties of image forming systems
    a. Resolution
       i. Point-spread function
       ii. Pupil function
       iii. Airy disk
       iv. Deconvolution
    b. Field-of-view
       i. Vignetting
       ii. Space-bandwidth issues

Imaging techniques
11. Photography
    a. Basics of photography and cinematography
    b. Satellite photography
12. Microscopy
    a. Wide field microscopy
    b. Laser scanning confocal microscopy
    c. Super-resolution microscopy
13. Multiphoton imaging
14. Lightsheet imaging
15. Miniaturized imaging systems
    a. Semiconductors (e.g. cell phone cameras)
    b. Fiber optic imaging (e.g. endoscopes)
    c. Miniaturized optical elements
16. Lidar
Fourier optics

17. Introduction to Fourier optics
   a. 4f imaging system
   b. Spatial light modulator

FINAL EXAM

Preview of the sequel to this course

Optics & Imaging B
2 lectures per week (17 lectures total), in-class midterm, final, in-class reviews for both exams

Optical systems
Basic lens schemes, Camera lenses, Objectives, Design software, Lasers

Prototyping systems
Components, Optomechanics, Alignment, Metrology

Practical fabrication
Tolerance analysis, Optomechanical design, Passive and active alignment

New optical elements
Adaptive optics, Metalenses, Negative index materials, Tunable lenses

Ultrafast optics
Characteristics of ultrafast pulses, Prechirping, Pulse front distortion

Advanced optical components
Acousto-optical modulators/deflectors, Electro-optical modulators

Computational imaging
Lightfield imaging, Tomography, Holography, Time reversal, Single pixel cameras

Developing new systems
Projects: Testing, evaluating, improving
Optics & Imaging B
2 lectures per week, in-class midterm, final, in-class reviews for both exams
Mondays & Wednesdays, 12:00-1:50 p.m.
Kerr Hall 2166a

Instructor: Spencer LaVere Smith
sls@ucsb.edu
sllslab.org
3101 BioE
Office hours: Tuesdays 12:30-1:00pm and by appointment

Spring 2019

Schedule

Apr 1: Lecture 1
Apr 3: Lecture 2
Apr 8: Lecture 3 LAB
Apr 10: No class - Lecture 4 online
Apr 15: No class - Lecture 5 online
Apr 17: No class - Lecture 6 online
Apr 22: Lecture 7 LAB
Apr 24: Lecture 8
Apr 29: Lecture 9

May 1: Review session 1
May 6: Review session 2

May 8: Midterm
May 13: Lecture 10 LAB
May 15: Lecture 11
May 20: No class - Lecture 12 online
May 22: No class - Lecture 13 online
May 27: No class – Memorial Day
May 29: Lecture 14 LAB

Jun 3: Lecture 15 LAB
Jun 5: Review
Jun 10-14: Final exam (to be scheduled)
Lectures & Labs

Building imaging systems
1. Design process
   a. Specification
      i. objectives, figures of merit
      ii. example: two-photon microscope
   b. Examining prior art
      i. example: photography lenses
      ii. example: microscope objectives
   c. Model and optimization software
   d. Tolerance analysis

2. Building process
   a. Prototyping
      i. Components
      ii. Optomechanics
      iii. Lab alignment
   b. Manufacturing
      i. Custom lens procurement
      ii. Optomechanical design
      iii. Passive and active alignment
      iv. Metrology

Fourier imaging
3. LAB The 4f correlator
   a. Principles of Fourier imaging
   b. Building the setup
   c. Examining the Fourier plane
   d. Filtering

Electronics
4. Data acquisition
   a. Hardware
      i. Area sensors, controllers, frame grabbers
      ii. Point sensors, controllers, digital acquisition
   b. Software
      i. Low-level hardware control
      ii. High-level system automation
      iii. Example: laser scanning software

Advanced optical elements and applications
5. Adaptive optics
   a. Deformable mirrors
      i. Aberration correction
      ii. Fast z-focus changes
   b. Spatial light modulators
      i. Time-reversal
      ii. Holography
   c. Metalenses
      i. Principles of design and operation
      ii. Example applications
   d. Tunable lenses
   e. TAG lenses
   f. Comparing fast-Z focus change technology
i. Electrically tunable lenses
ii. Electro-wetting lenses
iii. Remote focusing
iv. TAG lenses
v. Deformable mirrors

Nonlinear optics
6. Femtosecond laser pulses, SPDC
   a. Characteristics of ultrafast pulses
   b. Dispersion, prechirping, prechirper design
   c. Pulse front distortion
   d. Spontaneous parametric down-conversion (SPDC)

Beam steering
7. **LAB** Laser scanning system
   a. Principles of the scan engine
   b. Building the system
   c. Getting images
   d. Measuring performance

8. Fast steering and modulation
   a. Acousto-optical modulators/deflectors
   b. Electro-optical modulators

9. Ultrafast laser scanning microscopy
   a. Case study: MHz scanning
   b. Case study: two-photon tomography

**MIDTERM EXAM**

More lab work
10. **LAB** Aberrations
    a. Deformable mirror
    b. Wavefront sensor

Special topic in phase optics
11. Phase plates and head mounted displays

Advanced imaging topics
12. Extreme photography
    a. Large pixel counts (multi-sensors, stitching)
    b. Fast imaging (streak cameras, etc)

13. Light fields
    a. Single pixel cameras
    b. Lightfield imaging
    c. Holography

14. **LAB** Zemax
    a. System design
    b. Merit function
    c. Optimization

15. **LAB** LIDAR
    a. Principle of operation
    b. Building the system
    c. Getting images
    d. Measuring performance

**FINAL EXAM**
594 Neuroengineering: Measuring & Manipulating Neural Activity
(New class, In Development)

Instructor: Spencer LaVere Smith
s@ucsb.edu
sllab.org
3101 BioE

Course Description:
Fundamental research into brain function can inform neurobiology, artificial intelligence, and lead to advances in clinical therapies and brain-machine interfaces. Measuring and manipulating brain activity, across hundreds or thousands of neurons with the resolution of individual neurons, is challenging. It involves state-of-the-art engineering in an array of disciplines including optics, protein engineering, imaging, and electronics. We will cover the latest technology for these aspects of neuroengineering, and the prospects for further advances.
Biological Dynamics (MCDB 172, Fall 2021)

*It is not Nature that imposes Time and Space upon us; it is we who impose them upon Nature because we find them convenient.*  – Henry Poincare

Instructor: Max Wilson, Assistant Professor

**Course Description**
This course is an introduction to mathematical models and computer simulations used to describe and understand time varying biological systems.

**Learning Objectives**
- Survey mathematical methods for describing the dependence on time of biological phenomena.
- Illustrate how to construct mathematical models to gain insights into complex biological systems.
- Develop working knowledge of a python code base that enables future evaluation of common classes of models applied to the study of biological dynamics.

**Textbooks:**
*Nonlinear Dynamics and Chaos* - Steven Strogatz
*Modeling Life: The Mathematics of Biological Systems* - Garfinkel, Shevtsov, Guo

**Class Format:** Three 50min lectures per week and one 50min discussion section.

**TAs:** Need to have experience in python

**Required Materials:** Computer with python 3 installed.

**Evaluations:** Homework will count for 60% of the class grade and will include both pencil & paper mathematics as well as python notebook scripts. The Midterm and Final will each count for 15%. A final project will count for 10% of the final grade.

**Course Structure**

**Weeks 1-2: Systems of interacting parts**
- Mathematical Warm-up
  - Taylor Expansions
- Mathematical Warm-up
  - De’ Moivres Theorem
- Linear Algebra I
  - Matrices and Vector Spaces
  - Describe gene, cellular, and neural networks
- Linear Algebra II
  - Eigenvalues, eigenvectors, and stability
• Linear system analysis Red Blood Cell production

• PCA and SVD - Principles
  o Derive principles and equivalence
  o Show image analysis example

• PCA and SVD – Bio Examples
  o Analyzing RNA Seq Data
  o Analyzing Protein Dynamics

**Weeks 3-4: Biological systems in the time dimension**

• Numerical Integration
  o Euler's method
  o Code your own integrator

• 1D Linear Systems
  o Bacterial population growth
  o Electrical membrane potential

• 2D Linear Systems
  o Phase Plan
  o Genetic switches

• 2D Linear Systems
  o System classification
  o Gene regulation

• Mass Action Kinetics
  o Creating differential equations

• Perfect adaptation in biochemical networks
  o Derive different mass action models of adaptation
  o Simulate and compare three models

**Weeks 5-7: Nonlinear Biology**

• Introduction to Non-Linear Systems
  o Population growth

• Excitable Systems
  o Neurons
  o B. subtilis competence

• Bifurcations, Stable and Unstable Limit Cycles
  o Biochemical Switches

• Limit Cycles II
  o Metabolic oscillations
  o Calcium oscillations
  o Briggs–Rauscher Reaction

• Weakly Non-Linear Oscillators
  o Van der pol oscillators

• Coupled Oscillators
  o Kuramoto oscillator
- Synchronized Firefly
- Chaos - Introduction
  - Lorentz
  - Rossler
- Chaos – Biological Implications
  - Heart Ahythmias
  - Chaos in the brain

**Weeks 8-9: Fourier space, and the spatial dimension**
- Fourier Analysis
  - All periodic signals are sum of sines and cosines
  - Cell cycle regulated genes
- Fourier Transforms
  - Convolutions and Intuition for FT
  - Discrete Fourier transforms
- Fourier Space in Image analysis
  - Microscopy
  - CryoEM
- Pattern Formation I
  - Introduction to partial differential equations
  - Discrete Laplacian operator
- Pattern Formation II
  - Turing patterns in morphogenesis
  - BZ reaction

**Week 10: Final project presentations**

**Homework Assignments**

**HW1:**
1. Matrix multiplication
2. Dot product
3. Matrix inverse
4. Eigenvalues and eigenvectors
   a. Finding the e-vecs and e-vars of a 2x2 matrix
   b. What is the relationship to “diagonalization”?

**HW2:**
5. Principal component analysis and SVD
6. Variance and covariance
7. Covariance matrix

**HW3:**
8. Exponential function
a. Real exponents  
b. Complex exponents

9. 1D linear ODE  
a. What does “linear” mean?  
b. General vs particular solutions  
c. The simplest case: $dx/dt = kx$

10. Euler integration

11. 2D linear ODE  
a. Phase portraits  
b. Matrix representation  
c. General solution: eigenvector representation  
d. Trace-determinant plane

HW4: 1D case

12. Nonlinear ODEs in 1D  
a. What did linearity promise us?

13. 1D fixed points and stability

14. Characterizing 1D nonlinear ODEs  
a. Visually: phase portrait and trajectories  
b. Analytically (solving for FP, derivative test for stability)

15. Bifurcations in 1 dimension  
a. The bifurcation diagram

HW5: 2D case

16. Nonlinear ODEs in 2D

17. Stability in 2+ dimensions

18. The Jacobian matrix

19. Nullclines

HW6: Computational analysis of phase space

20. Visualizing phase space in python  
a. Plotting nullclines and trajectories

21. Bistability and the toggle switch

HW7: Chaos

22. Simulation and visualization of chaotic systems in multiple dimension

23. Determinism and sensitivity to initial conditions

24. Exploring parameter space

HW8: Fourier Analysis

25. Applying the DFFT to imaging data

HW9: Turing Models

26. Zebras vs Leopards: Reaction Diffusion models with random initial conditions
BIOEXXX Applied Machine Learning/Big Data:

New Course, In Development We expect this class to be developed and taught by a new FTE hire. Machine learning has potential in to analyze large, complex biological data sets. It is used often a pivotal tool in computational biology and bioinformatics. However, biological information is required in addition to machine learning for successful application. This class will focus on how big data/applied machine learning can be used for image processing and segmentation, genomics, proteomics, microarrays and systems biology.
BIOEXXX Signal Processing in Biology:

New Course, In Development We expect this class to be developed and taught by a new FTE hire. This course will be designed to introduce two fundamental concepts of signal processing: linear systems and stochastic processes. Various estimation, detection and filtering methods are developed and demonstrated on biomedical signals. The methods include harmonic analysis, auto-regressive modeling, Wiener and Matched filters, linear discriminants, and independent components. All methods will be developed to answer concrete question on specific data sets in modalities such as ECG, EEG, MEG, Ultrasound.
ChE 154: Engineering Approaches to Systems Biology
Instructor — Sid Dey

Course objectives:
● Learn about the central dogma of biology and how biological processes are regulated within cells.
● Existence of network motifs in biological circuits and their role in regulating the dynamics of gene expression within cells.
● Motifs in other biological networks, such as developmental and signal transduction networks.
● Model these biological network motifs using a variety of systems engineering methodologies.
● Role of stochasticity in biological processes and model these systems analytically using chemical master equations and numerically using the Gillespie algorithm.
● Methods for analysis of complex networked systems, including robustness analysis.
● Strategies for constructing mathematical modeling of biological systems, including the strategic issues of model structure determination, parameter estimation, model validation, and design of experiment.
● Work on a research problem from the scientific literature and critically read and analyze the results presented in these papers.
● Work on reproducing and validating model results that have previously been presented in the literature.
● Work in teams on an open-ended problem and present results as an oral in-class presentation and as a written report.

Learning Objectives:
● Quantitatively model biological networks to understand the behavior of dynamical systems.
● Survey papers and effectively critique scientific literature in the area of Systems Biology.

Design Project:
● Students will work on a research problem in groups of 2.
● The goal of the project is to pick a paper that involves principles of systems biology where the authors have modeled biological circuits to gain new insights into mechanisms of cellular regulation.
● After discussing with the instructor/TA, students will pick a paper by the end of week 6.
● The students will then work on reading the paper and reproducing/validating the mathematical models and results presented in the paper. Students will submit a final 3-page written report of their results in week 10 and present their work during the final examination as an oral presentation.

Major Topics Covered (lecture and lab/discussion): Each lecture in the following schedule is 75 minutes long.

<table>
<thead>
<tr>
<th>Lecture #</th>
<th>Topics</th>
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<tbody>
<tr>
<td>1</td>
<td>Introduction to systems biology</td>
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<tr>
<td>2</td>
<td>Central dogma of biology and basic concepts</td>
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<tr>
<td>3</td>
<td>Dynamics of simple gene regulation</td>
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<tr>
<td>Lecture and Lab: Three hours of lectures per week</td>
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<td>------------------------------------------------</td>
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<tr>
<td><strong>Textbook:</strong> “An Introduction to Systems Biology: Design Principles of Biological Circuits” by Uri Alon</td>
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<tr>
<td><strong>Optional supplemental reading:</strong></td>
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<tr>
<td>1. “Physical Models of Living Systems” by Philip Nelson</td>
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<tr>
<td><strong>Prerequisites:</strong> Chemical Engineering 170 or 107; Mathematics 4B or 4BI; Mathematics 6A or 6AI and Mathematics 6B. If these prerequisites are not met, students can contact instructor to discuss if they have the necessary background to take this class.</td>
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ChE 173/272: ‘Omics’ Enabled Biotechnology (Spring 2017)
UCSB Department of Chemical Engineering

Lectures: T/R 12:30-1:45pm in Engineering II - 1519
Web Page: https://gauchospace.ucsb.edu/ (please see instructor if not enrolled)
Credits: 3

Instructor: Prof. Michelle A. O’Malley
3343 Engineering II
momalley@engineering.ucsb.edu
Tel: (805) 893-4769
Office Hours: TBA

Teaching Assistant: Sean Gilmore
3311 Engineering II
seangilmore@umail.ucsb.edu
Office Hours: TBA

“Textbook”:
Due to the rapidly changing nature of this field, there is no adequate, up to date, textbook! Rather, I will post papers from the literature on Gauchospace, which will supplement the content of these two textbooks below (relevant chapters will be posted online for you):

- (IG) Introduction to Genomics, Lesk, 2nd ed. (2012)

It is up to you whether you want to purchase them (they are paperback, and fairly cheap). Additionally, any cell biology textbook will do to refresh your molecular & cellular biology knowledge. I suggest these (you likely already have them):


Course description and objectives:
This course will integrate genomic, transcriptomic, metabolomic, and proteomic approaches to quantify and understand intricate biological systems. Complementary bioinformatics approaches to curate the large datasets associated with these experiments will also be discussed. Recent examples from the literature will reinforce core concepts, ranging from applications to human health to the environment. By the end of the course, you should be able to design an integrated experiment that capitalizes on these "omics"-based approaches to enhance the scope of your own research.

Key course activities:
- You will put together a short research proposal to a user facility based on your own research or thesis project. This proposal will incorporate at least 2 of the ‘omics’ tools that we will cover. My hope is that you will be able to submit such a proposal to enhance the scope of your research (plus, it’s a great experience in proposal writing!). 3 of the assignments will serve to develop the content of your proposal, and peer review will refine your proposal writing skills.
- As a class, we’re going to put our skills to the test by sequencing and analyzing the genome of a novel organism! To do this, we will leverage the newly acquired Illumina NextSeq at the CNSI BNL core facility. More details will follow, but should include a brief lab tour & in-house bioinformatic analysis. 1 of the assignments will focus on this effort.
- A take-home final exam will be distributed during the last week of the course, and will be due during finals week.
Some Notes on the Course:

- **This is not your average "bio" class!** In contrast to the content of many other courses, the subject matter is changing daily. For that reason, we will strive to balance “textbook” material with real world applications and discussion, including a data analysis component. The goal of the course is to enable you to incorporate “omics” based technologies into your own research – whether you already use them or have never relied on them before.

- **Utilize supplemental resources (and bring them to our attention!)** To enhance understanding of the material, we will focus on research papers and group discussions. We will also frequently use web-based tools to analyze data. If you know of such a tool (or a paper from the literature) that we should talk about – let us know!

- **Check Gauchospace often.** Gauchospace will be used to post announcements relevant to the course. Frequently, supplemental reading materials will be posted on the site that are associated with different topic areas – please make sure to read them! (additionally, make sure your email is linked to Gauchospace)

- **Participate and ask questions.** Chances are that if you have a lingering question about a concept, several of your fellow students will share the same question – so please ask! Wherever possible, class discussion is encouraged, which will serve to enhance core concepts.

- **Utilize the office hours.** Since this class will move at a fast pace, please feel free to visit the TA and the instructor regularly during office hours to discuss and clarify difficult material.

- **Please hand in assignments on time.** Assignments will be collected at the beginning of class. If you will be out of town for a conference visit, please arrange to hand in the assignment with the TA before you leave.

- **For questions on grading...** For questions on assignment grading, please see the TA/instructor within one week of receiving the graded material back. Please be aware that several measures are taken to ensure consistency in grading. If you have a question on the grading of a particular item, please summarize your concern in writing and submit it to the TA or the instructor – just be aware that the entire assignment or exam will be subject to regrading.

Finally, some clarification that I need to provide as per UCSB policy:

- **Turn in original work.** Academic dishonesty is considered a serious offence, and will be dealt with as such. Please refer to this website as a refresher regarding our campus policies on academic integrity: [http://judicialaffairs.sa.ucsb.edu/CMSMedia/Documents/academicintegflyer.pdf](http://judicialaffairs.sa.ucsb.edu/CMSMedia/Documents/academicintegflyer.pdf)

You are encouraged to work together on assignments, but make sure that you hand in your own original work. Any part of an assignment that is clearly copied from a fellow classmate or plagiarized from a published source is not original work. Students involved will be referred to Judicial Affairs.
**Tentative Agenda and Important Dates (just like life, this course will evolve!)**

<table>
<thead>
<tr>
<th>Week</th>
<th>Dates</th>
<th>Topic Area</th>
<th>Reading</th>
<th>Due</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T 4/11; R 4/13</td>
<td>Introduction &amp; Omics overview</td>
<td>(review); GS</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>T 4/18; R 4/20</td>
<td>Genomics &amp; Metagenomics</td>
<td>GS; DGPB Chp. 2; IG Chp. 1,3,6-7</td>
<td>Assignment #1 (4/20)</td>
</tr>
<tr>
<td>3</td>
<td>T 4/25; R 4/27</td>
<td>Genomics &amp; Metagenomics</td>
<td>GS; DGPB Chp. 2; IG Chp. 1,3,6-7</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>T 5/2; R 5/4</td>
<td>Transcriptomics &amp; Gene Expression</td>
<td>GS; IG Chp. 9</td>
<td>Assignment #2 (5/4)</td>
</tr>
<tr>
<td>5</td>
<td>T 5/9; R 5/11</td>
<td>In-class Genome Analysis Project</td>
<td>GS; IG Chp. 9, 3,11</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>T 5/16; R 5/18</td>
<td>Proteomics</td>
<td>GS; DGPB Chp. 8; IG Chp. 10</td>
<td>Assignment #3 (5/18)</td>
</tr>
<tr>
<td>7</td>
<td>T 5/23; R 5/25</td>
<td>Metabolomics</td>
<td>GS; IG Chp. 11</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>T 5/30; R 6/1</td>
<td>Integrating Methods, Validation &amp; Modeling</td>
<td>GS; DGPB Chp. 12, IG Chp. 11</td>
<td>Assignment #4 (6/1)</td>
</tr>
<tr>
<td>9</td>
<td>T 6/6; R 6/8</td>
<td>Integrating Methods, Validation &amp; Modeling</td>
<td>GS; DGPB Chp. 12, IG Chp. 11</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>M 6/12 (3pm)</td>
<td></td>
<td></td>
<td>Final Exam Due</td>
</tr>
</tbody>
</table>

*GS*: posted on Gauchospace in appropriate folder for the indicated week  
*DGPB*: Discovering Genomics, Proteomics, & Bioinformatics  
*IG*: Introduction to Genomics  
*TBA*: To Be Announced

**Grading Breakdown Details**  
*Assignments* 40%  
*Course Participation* 20%  
*Final Exam* 40%
New ChE Elective Course Proposal

Course: ChE 174: Model-Guided Engineering of Biological Systems

Total Units: 3, letter grade only

Class Schedule: Three one-hour lectures per week.

Instructor: Prof. Arnab Mukherjee

Course Description: ChE 174 will introduce students to fundamental principles underlying synthetic biology with an emphasis on mathematical modeling of gene regulation using ordinary differential equations and mass action kinetics. Students will be introduced to foundational concepts in molecular and cellular engineering, synthetic biology, quantitative modeling of various genetic circuits, as well as cutting edge applications of innovative molecular biotechnologies such as cancer immunotherapy and cell-based diagnostics. Students will also learn to design and predict the functional outcomes of synthetic gene circuits and review primary literature in the field. At the end of this course, students are expected to develop a quantitative understanding of genetic circuit design as well as understand how a quantitative engineering-focused approach to the life sciences is driving entirely new advances in the healthcare, security, and manufacturing sectors.

Prerequisites: ChE10; ChE 107 or equivalent, or consent of instructor.

Grading Criteria:

<table>
<thead>
<tr>
<th>Assignments</th>
<th>40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team project (Critiques)</td>
<td>25%</td>
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<tr>
<td>Peer review</td>
<td>5%</td>
</tr>
<tr>
<td>Final Exam</td>
<td>30%</td>
</tr>
</tbody>
</table>

Topics to be covered:

1. Introduction to synthetic biology – broad overview, fundamental tenets of synthetic biology, analogies with electrical engineering, goal of the field, basic differences with classical biochemical or bioprocess engineering


3. Control & regulation of information flow in biological systems – transcription factors, lac operon as a model system to understand biological control, RNA-based control of gene expression, epigenetic control mechanisms

4. Enabling technologies for engineering biomolecules and cells – recombinant DNA technology, plasmids, restriction enzymes, polymerase chain reaction, protein engineering, measuring/quantifying gene expression (fluorescent reporters, quantitative RT-PCR)
5. Modeling gene circuits – simple transcription, mass action kinetics, dynamic and steady state analyses, phase plane portraits for 1D systems, steady states and stability, time-scale separation (transcription vs. translation), response time, robustness, inducible transcription, binding isotherms, hyperbolic dose response, circuit tuning via binding constant and degradation rates, allostery, and switching, sigmoidal dose response, examples of common inducible repressors and activators in bacteria (e.g., lacI, araC, tetR, luxR, ci, ci857)

6. Feedback – negative feedback, advantages of negative feedback (robustness, gain, response time), positive feedback, emergence of bistable behavior, hysteresis. Examples of feedback regulated gene circuits in natural systems (case study: insulin production)

7. From circuits to networks – building an invertor (layered repressors), circuit tuning via allostery and binding constant, 5-gene network for concentration band detection (case study: hypoxia activated drug production)

8. From circuits to networks – coherent feed forward networks with AND function, delayed response, pulse filtering, incoherent feed forward network with AND function, pulsed output, pattern formation with gene networks (case study: probiotic cell-based therapy)

9. Literature survey – mind control of genetic networks for therapeutic delivery (Fussenegger), toggle switch (Collins), repressilator (Elowitz), autonomous population control (You), counters (Collins), synchronized oscillator (Hasty)

10. Stochastic simulations of biochemical systems (advanced topic, time permitting)
New Course, In Development  We expect this class to be developed and taught by a new FTE hire. Students will learn to navigate major bioinformatics databases such as reference genomes, GEO, or Biomodels and define the identifying systems for one or more bioinformatics pathways relevant to their interests (e.g., Accession Numbers, Gene Ontology IDs, KEGG Identifiers, etc.). Students will learn to determine variation between two individuals at the single gene and at the genomic level and learn to design primers to manipulate a specific gene for different downstream applications (e.g., molecular engineering in mutation sites; measuring expression with quantitative PCR) At the end of the course students should be able to read and construct plasmid maps and restriction digest maps as well as read and interpret reference sequence data from NCBI Nucleotide database. They will be expected to analyze next generation sequencing data, from raw data input to the computational pipeline through quantification of expression differences and visualization of results and identify and interpret epigenetic or chromatin signatures from experimental data.
**BIOEXXX Molecular Engineering:**

*New Course, In Development* We expect this class to be developed and taught by a new FTE hire. Students will learn to recognize the various techniques for engineering the structures of biomolecules and identify potential sites for bio-orthogonal modification. The class will demonstrate how structural and electrochemical properties of single molecules predict their higher-order assemblies, and describe the biomedical and biomanufacturing applications of purpose-built biomolecules.
BIOEXXX I/O Hacking Biology:

New Course, In Development We expect this class to be developed and taught by a new FTE hire. In this class students will be taught to recognize the importance of tools for reading the activity states of proteins, genes, cells and organisms. We will discuss the significance of programmable inputs in manipulating and engineering biology. By the end of the course, students will be able to design and model their own feedback controlled biological system.
Course Syllabus

Synthetic Biological Design, Control and Computing
ME225EY/ME125EY - Winter 2019
University of California Santa Barbara

Course Personnel

Instructor: Enoch Yeung, Assistant Professor, Mechanical Engineering
Email: eyeung@ucsb.edu
Office: BioEn 3104
Office Hours: Thur 3-3:30 pm

TA: Dennis Joshy, ME Graduate Student
Email: dennis00@ucsb.edu
Office Hours: TBD

Location and Schedule

Room: HSSB 1211
Time: TR 3:30-4:45

Required Textbooks:


Course Description:

This course introduces the basics of design of synthetic biological systems, including the architecture of genetic networks, circuits, and pathways controlling engineered biological function, as well as single-cell microbial behavior, and microbe population dynamics. This course also will provide a gentle introduction to workflows in biomolecular engineering, genetic circuit design, genomic editing, as well as principles of experimental design. An overview of various engineered and natural biological functions is provided, including multi-stability, biological oscillations, stochastic effects in genetic circuits, robustness of circuit performance, and cellular capacity.
Prerequisites

Strong familiarity with dynamics, linear algebra, ordinary differential equations (ME16, ME17), and probability (PSAT120A-C, P160A) is highly recommended. Completion of courses in control theory, molecular biology, microbiology, and systems biology are also encouraged.

Course Objectives

This course should enable students to:

1. Reason about transcriptional and translational processes as dynamical systems
2. Design, convert, and simulate conceptual models of genetic circuits into dynamic quantitative models
3. Reason about gene regulation, allosteric induction, and chemical reaction networks with input-output models
4. Identify the role and effect of feedback regulation in biological systems as nonlinear control processes
5. Design sequence-to-part-circuit workflows for constructing basic genetic circuits
6. Reason about the role of circuit context and its impact on circuit design and performance

Course Topics

A tentative list of topics is provided here:

1. Transcription and Translation: Core Processes (Chapters 2-3 in Alon, Chapter 2 in Del Vecchio)
2. Dynamic Behavior of Genetic Circuits (Chapter 3 in Del Vecchio)
3. Input-Output Behavior of Genetic Circuits (Appendix A, B in Alon, Select Papers from the Literature)
4. Design Workflows and Cloning (Select Papers from the Literature)
5. Interconnecting Biological Components (Chapter 6 of Del Vecchio)
6. Design Tradeoffs of Synthetic Genetic Networks (Chapter 7 of Del Vecchio)
7. Genetic Circuits as Stochastic Systems (Chapter 4 of Del Vecchio).

During the quarter, course topics may be adjusted to support the needs of the class.
Assignments/Grading

Homework will be assigned weekly, accompanying two lectures and the corresponding reading material. No final exam will be administered, but a final essay will be required of each student consisting of a hypothetical research proposal based on the topics learned in class. Homework will contribute 90% towards the final grade, while an final essay called the research plan will contribute 10% towards the final grade. There will be no final exam. In the event of an outstanding research plan, I will take the research plan as 100% of the grade. The converse will not be true (a poor proposal grade will not replace all homework grades).

Homework will be evaluated based on correctness of approach, as well as the ability to obtain the correct answer (where appropriate). Partial credit will be awarded for attempted solutions with a correct approach.

The research plan will consist of a single spaced 5-6 page document outlining a clear plan for addressing a research question. The format of the proposal will be roughly:

- 2 pages for technical background, preliminary findings, literature review

- 2 pages describing methods and approach, including a detailed plan of experiments, milestones, stopgates, etc

- 1-2 pages describing the novelty and impact of the proposed research

Proposals will be evaluated based on technical feasibility, novelty, clarity, and articulation of impact.
## Course Schedule

<table>
<thead>
<tr>
<th>Dates</th>
<th>Topics</th>
<th>Reading</th>
<th>HW Assigned</th>
<th>HW Due</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/7-1/13</td>
<td>Modeling Core Processes</td>
<td>BFS Ch.2</td>
<td>HW1: 2.1, 2.4, 2.9, 2.10</td>
<td>None</td>
</tr>
<tr>
<td>1/14-1/20</td>
<td>Derivation of RREs, Mass Action</td>
<td>BFS Ch.2</td>
<td>HW1</td>
<td>None</td>
</tr>
<tr>
<td>1/21-1/27</td>
<td>Modeling Dynamical Behavior</td>
<td>BFS Ch.3</td>
<td>HW2: 3.1-2, 3.5-6, 3.10</td>
<td>None</td>
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<tr>
<td>1/28-2/3</td>
<td>Review of Controls &amp; Prob. Theory</td>
<td>None</td>
<td>None</td>
<td>HW2-3</td>
</tr>
<tr>
<td>2/4-2/10</td>
<td>IO Modeling of Genetic Circuits</td>
<td>website</td>
<td>HW3: 6.1-6.4</td>
<td>HW1</td>
</tr>
<tr>
<td>2/11-2/17</td>
<td>Stochastic Modeling</td>
<td>BFS Ch.4</td>
<td>HW5: 4.1-4.5</td>
<td>HW4</td>
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<tr>
<td>2/18-2/24</td>
<td>Genetic Circuit Design</td>
<td>website</td>
<td>HW6: website</td>
<td>HW5</td>
</tr>
<tr>
<td>2/25-3/3</td>
<td>Circuit Cloning Workflows</td>
<td>website</td>
<td>HW7: website</td>
<td>HW6</td>
</tr>
<tr>
<td>3/4-3/10</td>
<td>System ID of Genetic Circuit Models</td>
<td>website</td>
<td>HW8: website</td>
<td>HW7</td>
</tr>
<tr>
<td>3/11-3/17</td>
<td>Circuit Interconnection Theory</td>
<td>BFS Ch.6</td>
<td>HW9: 6.1-4</td>
<td>HW8</td>
</tr>
<tr>
<td>3/18-3/24</td>
<td>Design Tradeoffs</td>
<td>BFS Ch.7</td>
<td>HW10 7.1, 7.2, 7.4</td>
<td>HW9</td>
</tr>
</tbody>
</table>

Table 1. Homework assignments and reading are subject to change, please check the website for the latest assignments.
Syllabus

Term: Winter Quarter 2018
University Course Number: CS 211B (cross-listed ME/ECE/MATH/ChemE/Geol)
Course Title: Numerical Simulation
Professor:

- Linda R. Petzold, Mechanical Engineering, and Computer Science
- Phone: (805) 893-5362
- Email: petzold@ucsb.edu
- Office: 3106 Bioengineering
- Office hours: Fridays 3-5pm, or email for appointment

Reader:

- Arya Pourzanjani
- Email: arya@umail.ucsb.edu
- Contact: Please contact Arya by email if you have a question about grading
- Office hours: TBD, or email for appointment

GauchoSpace: All assignments and announcements will be posted on GauchoSpace. This includes any class cancellations or office hour cancellations or rescheduling. You are responsible for looking there regularly to find any news. You can also find your grades there! The site is https://gauchospace.ucsb.edu/.

Course Days/Times Meet on Campus: Monday and Wednesday 9-10:50, Phelps 3526

Course Description:


Expected Outcomes:

1. Understanding of fundamental concepts of numerical solution of ODEs, including sources and propagation of error, and stiffness
2. Experience with practical issues of software development including error control and stepsize selection
3. Capability of applying stability and accuracy concepts from numerical ODEs to numerical PDEs

Grading Policy:

- 2 Exams 50%
- Classroom participation 10%
- Homework 40%

Course Schedule:

Exams:

- Monday, February 4 - Exam 1
- Wednesday, March 13 - Exam 2
Exams: The two exams are each worth 25% of the final grade. Exams will be in-class, closed-book, no electronic devices. Bring paper to write on, and a stapler or fastener. Label all sheets of paper with your name. You are allowed and encouraged to bring one standard sheet of notebook paper with notes written on it (it is OK to write on both sides).

Homeworks: Homeworks are due at 9am (beginning of class). If you need to turn in a homework early, you can turn leave it in the Inbox just outside my office door (Bioengineering 3106), inside a sealed envelope. **Late homeworks will not be accepted**, because we will discuss the homework solutions in class on the day they are due. There will be programming homeworks, starting in week 2. Programming assignments should be done in Matlab or in a language that has been approved by the TA. You are not allowed to use Matlab (or other) functions which would defeat the point of the exercise. (For example, if the exercise is to write an ODE solver, do not call one of Matlab’s ODE solvers unless the exercise explicitly says to do it, or unless you are doing it to compare with and check the accuracy of the ODE solver you have just written. If you are in doubt about whether you can use one of Matlab’s functions, ask me). Turn in your source code on GauchoSpace. Comment the code! Turn in the results (plots, usually) specified in the assignment, on paper. Label the plots! A lack on comments and/or labels could result in a reduction in your grade for the assignment.

Classroom participation: At the beginning of each class period, we will review the most important concepts from the previous lecture. I may call upon you, by random selection, to review a given concept. I may give you a problem to work on the board, with the help of the class. During the class period, I may ask questions which anyone can volunteer to answer. For class periods where a homework was due, we will go over the homework problems in a similar manner. If you do a reasonably good job, you will get a +; if you are absent or if it is obvious that you don’t know what you are talking about, then you will get a -; if you do an absolutely great job, you will get a ++. Your grade for classroom participation will be given by the sum of these scores (since we cannot ensure that everyone gets an equal number of opportunities). There may also be other opportunities for classroom participation. A positive (or zero) total will yield the full points for this category; a negative total will yield 0 points. The purposes of classroom participation are to ensure that you are up to date on your reading and understanding of the course material so
that you are able to get the most out of each lecture, to help you to prepare for oral exam situations, and to provide me with information about your level of understanding, so that I can adjust my lectures accordingly. If you consistently attend class and stay up to date on the reading material (after each class, read over the text sections that we covered, and think about what are the most important concepts, and read the other assigned material on a timely basis), you should easily be able to get the full points in classroom participation.

Feedback: You are encouraged to ask questions during the lecture if there is anything you don’t understand. However, this will not count as classroom participation. Please, come to the office hours, particularly if there is something you don’t understand that would require a longer explanation than is possible in class. You are welcomed and encouraged to send questions, comments or suggestions about the course to me or to the TA. You can do this by email or, if you prefer to do it anonymously, by putting it into the Inbox just outside my office door.
MATRL 270: Biomaterials and Biosurfaces
Angela Pitenis

Schedule

Winter 2019: MW 4:00 to 5:15 pm, Phelps building, room 1417

Course description

The first part of this course will cover the fundamentals of natural and artificial biomaterials with an emphasis on surface and contact mechanics. The second part will focus on biological surfaces (biosurfaces) and delve into molecular-level structure and function. The third part will explore the dynamic interactions between biomaterials and surfaces with the body and designing for biocompatibility.

Topics to be covered

- **Introduction to biomaterials**: overview of medical devices, implant complications, FDA approval process.
- **Surfaces and interfaces**: measuring and characterizing surfaces, asperity contacts, the real area of contact, intermolecular and surface forces, Lennard-Jones potential, Hertzian contact mechanics theory, adhesion, Johnson-Kendall-Roberts theory, contact hysteresis.
- **Introduction to biosurfaces**: overview of biopolymer physics, soft biological molecules and surfaces, lipids, proteins, fibrous molecules, biological membranes, hydrophilic and hydrophobic interactions, bio-specific and non-equilibrium interactions. Basic biological and biochemical systems reviewed for non-biologists.
- **Dynamic biointeractions**: Cell-matrix interactions, the immune system, wound healing, hard and soft implants, device complications, revisions, designing for biocompatibility.

Textbooks

- No textbook required.

Grading system

- Homework (20%)
- Oral presentation on related topic (40%)
- Written report on related topic (40%)
<table>
<thead>
<tr>
<th>Date</th>
<th>Lecture</th>
<th>Topic</th>
<th>Notes</th>
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<tbody>
<tr>
<td>2018-01-07</td>
<td>1</td>
<td>Intro to Biomaterials</td>
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<tr>
<td>2018-01-09</td>
<td>2</td>
<td>Rough Surfaces</td>
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<tr>
<td>2018-01-14</td>
<td>3</td>
<td>Contact Mechanics</td>
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<tr>
<td>2018-01-16</td>
<td>4</td>
<td>The Real Area of Contact</td>
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<td>2018-01-21</td>
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<td>Martin Luther King, Jr. Day</td>
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<tr>
<td>2018-01-23</td>
<td>5</td>
<td>Adhesion</td>
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<td>2018-01-28</td>
<td>6</td>
<td>Fragile Objects</td>
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<td>2018-01-30</td>
<td>7</td>
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<td>MROP 2019</td>
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<tr>
<td>2018-02-04</td>
<td>8</td>
<td>Introduction to Cell Biology</td>
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<td>2018-02-06</td>
<td>9</td>
<td>Biological Membranes</td>
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<td>2018-02-11</td>
<td>10</td>
<td>Interactions Between Membranes and Structures I</td>
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<tr>
<td>2018-02-13</td>
<td>11</td>
<td>Interactions Between Membranes and Structures II</td>
<td></td>
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<td>2018-02-18</td>
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<td>—</td>
<td>Presidents’ Day</td>
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<td>2018-02-20</td>
<td>12</td>
<td>Dynamic Biointeractions</td>
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<tr>
<td>2018-02-25</td>
<td>13</td>
<td>Cell-Matrix Interactions</td>
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<tr>
<td>2018-02-27</td>
<td>14</td>
<td>Context</td>
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<tr>
<td>2018-03-04</td>
<td>15</td>
<td>The Immune System &amp; Wound Healing</td>
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<tr>
<td>2018-03-06</td>
<td>16</td>
<td>Hard Implants and Complications</td>
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<tr>
<td>2018-03-11</td>
<td>17</td>
<td>Soft Implants and Complications</td>
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<tr>
<td>2018-03-13</td>
<td>18</td>
<td>Designing for Biocompatibility</td>
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ME 125/225 RS – Engineering Biomaterials  
Winter 2020  
Syllabus

Course Information
Location: Engineering II, Room 2243  
Tues/Thurs. 2:00-3:15 pm

Instructor:  
Ryan Stowers, Ph.D.  
Department of Mechanical Engineering  
Office – Bioengineering 3201C  
Email - rstowers@ucsb.edu  
Office Hours: Mon. 3-4, Wed. 1-2 pm

Teaching Assistant:  
Marcela Areyano  
m_areyano@ucsb.edu


Description: This lecture-based course will provide an overview of material structure-property relationships, processing, and characterization techniques for metals, polymers and ceramics. We will discuss the unique design constraints imposed by the human body and discuss strategies to enhance biocompatibility. Throughout the course, emphasis will be placed on applications of biomaterials engineering in medical devices.

Objectives:
At the end of this course the students should be able to:
a) Describe what is meant by the term "biomaterials"
b) Explain basic principles of biocompatibility and implant performance  
c) List different strategies to modify and/or design materials that are biocompatible  
d) Describe how materials are fabricated  
e) Explain what biodegradability is and how it affects biomaterial design  
f) Describe specific applications of biomaterials  
g) Read, understand and assimilate papers, publications and lectures pertaining to the field of biomaterials and have broad understanding of biomaterials research

Grading

Exams – 50% (2 in class exams = 15% each, final exam = 20%)  
Problem Sets – 30%  
Project – 20%

Problem sets must be turned in by the start of class (2:00 pm). Late problem sets will not be accepted. The lowest problem set grade will be dropped.
<table>
<thead>
<tr>
<th>Date</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan. 7</td>
<td>Course introduction, history of biomaterials</td>
</tr>
<tr>
<td>Jan. 9</td>
<td>Surface properties</td>
</tr>
<tr>
<td>Jan. 14</td>
<td>Protein Adsorption</td>
</tr>
<tr>
<td>Jan. 16</td>
<td>Material Structure</td>
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<tr>
<td>Jan. 21</td>
<td>Strengthening, Phase Diagrams</td>
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<tr>
<td>Jan. 23</td>
<td>Polymers I</td>
</tr>
<tr>
<td>Jan. 28</td>
<td>Polymers II</td>
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<tr>
<td>Jan. 30</td>
<td>Hydrogels</td>
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<tr>
<td>Feb. 4</td>
<td>Exam 1</td>
</tr>
<tr>
<td>Feb. 6</td>
<td>Biomaterials for Drug Delivery</td>
</tr>
<tr>
<td>Feb. 11</td>
<td>Ceramics</td>
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<td>Feb. 13</td>
<td>Composites</td>
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<tr>
<td>Feb. 18</td>
<td>Natural polymers and tissue mechanics</td>
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<td>Feb. 20</td>
<td>Blood-Material Interactions</td>
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<tr>
<td>Feb. 25</td>
<td>Cardiovascular Applications</td>
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<tr>
<td>Feb. 27</td>
<td>Exam 2</td>
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<td>Mar. 3</td>
<td>Orthopedic Applications</td>
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<tr>
<td>Mar. 5</td>
<td>Failure</td>
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<tr>
<td>Mar. 10</td>
<td>Tissue engineering and regenerative medicine</td>
</tr>
<tr>
<td>Mar. 12</td>
<td>Project Presentations</td>
</tr>
</tbody>
</table>
ME225BP Methods in Mechanobiology and Biofabrication
Instructors — Beth Pruitt

Course Description:
- Cell mechanobiology topics including cell structure, mechanical models, and chemo-mechanical signaling
- Review and apply methods for controlling and analyzing the biomechanics of cells using traction force microscopy, AFM, micropatterning and cell stimulation
- Practice and theory for the design and application of methods for quantitative cell mechanobiology
- Weekly lecture and hands-on laboratory sessions.

Learning Objectives:
- Describe elements of cells which govern cell mechanical properties and force generation, describe critical terms and methodologies of cell biomechanical measurements, and catalog advantages and disadvantages of each
- Explain and demonstrate the role that analysis and modeling play in mechanobiology and designing quantitative experiments
- Define “mechanism” in the context of Mechanobio and Biochemical signaling and discuss approaches for dissecting signaling pathways
- Describe equilibrium, constitutive, and kinematic relationships of cell mechanics and measurement methods using mathematical, verbal and visual means
- Measure cell and material mechanical properties and choose appropriate material models to describe cell mechanics
- Explain limitations of imaging and displacement measurements and subsequent analyses of cell traction forces
- Define an open research problem in the context of the literature, propose appropriate methods to test a mechanobiology hypothesis, and develop a clear and concise research proposal including synthesis of prior art, aims, hypotheses and methods

Website: we will use gauchospace for upload and download of course materials
Attendance: mandatory at all labs, makeup sessions will not be available
Homework: Homework assignments due as specified
Location: lectures in ME classroom, labs TBA each week
Lectures: TR 12:30-1:45
Labs: TBD
Enrollment: By permission of instructor. Limited enrollment by laboratory constraints.
Safety: All students must complete the required lab safety training and certifications in advance of the second class. See Gachospase for details
Textbooks: Jacobs, Introduction to Cell Biomechanics and Mechanobiology, Garland Science
**Prerequisites:** The course assumes an engineering background but is structured to be accessible to graduate students in life sciences who have a strong physics and math background and engineering graduate students with basic biology knowledge.
Structure and Function of Biological Materials (Wet and Dry with labs)
Instructors — Kevin Plaxco, Ryan Stowers

Course Description:
Build course modeling tissues and cells using combination of biomechanics approaches, biomaterials models and transport models along with case studies of journal papers showcasing multi-scale and multi-mode analyses and experiments:

- **Biomechanics:** Force/displacement assays, traps, rheology, AFM
  - Bridge to biomaterials using models relating structure to function
- **Biomaterials:** elasticity, viscoelasticity, molecules, cells, tissues, entropic springs, polymer theory
  - Bridge to biomaterials by permeability, diffusion, signaling
- **Transport:** basic fluid models, diffusion, e.g. blood-brain barrier, tissue engineering as diffusion/transport limited, mechanosignaling

Choose appropriate models and assays
- What is your hypothesis?
- What will you measure to test your hypothesis?
- What statistics to test significance?
- What are your controls?

Examples:
- Solid: tumor progression vs tendon rupture (structure, rate differences)
- Fluid Flow: blood, urine, csf, lymph (fluid viscosity, flow rate differences)
- Transport across Interface: lung, kidney, gut, blood-brain barrier (gas/fluid/solid transport differences, waste/nutrient exchange)

Learning Objectives:

**Introduction to Materials and Structure in Biology**
- Hierarchical architecture: Molecules -> cells -> tissues
- protein structure and biopolymer networks
- entropic springs
- polymer theory
- Methods
  - Visualization (live vs. fixed, EM), scanning AFM
  - Identification: antibodies, NMR, chemical composition, crystallography

**Mechanics of biological materials**
- Elasticity – young’s modulus
- Viscoelastic – shear modulus, loss modulus
- Methods:
  - Force/displacement assays from AFM to tensile testing
  - Traps
  - Rheology

**Fluid mechanics and Transport**
- control volumes
- continuity
- laminar flow
- shear stress
- navier stokes
- Diffusion and Permeability
- Charge
- Methods:
  - PIV
  - Permeability
  - Rheology

**Format:** Lecture Only with demonstrations in core facilities

**Textbook:** Ratner, “Biomaterials” and primary literature

**Prerequisites:** Quantitative Experiments; and Biomolecular and Biochemical Methods; or permission of instructor
BIOEXXX Cell and Tissue Engineering: Cell and tissue engineering are rapidly growing fields within bioengineering. This course will examine fundamental biological processes and engineering tools essential to cell and tissue engineering both at the single-cell and the whole-organism levels. Topics include stem cell engineering, cell–matrix and cell–scaffold interactions, cell–cell interactions and tissue morphogenesis, wound healing, and in vitro organogenesis.
Pattern Formation and Self-Organziation  
*ME 211*

**Course Description**

- This is an introductory course to the processes of pattern formation and self-organization in natural systems (physical and biological systems) as well as in engineering. The goal of the course is to explain how ordered spatial structures appear in different systems. We will discuss the common aspects and the differences in the mechanisms that establish the patterns, and introduce various techniques used in different disciplines to study the formation of spatially extended structures. Some examples of the course topics (ordered by discipline) include:

**Physics**
- Crystal formation.
- Reaction-diffusion systems.
- Rayleigh-Bénard convection.
- Viscous fingering.

**Biology**
- Early embryo segmentation in the fruit fly.
- Leaf-venation patterns.
- Organ branching morphogenesis.
- Phyllotaxis.
- Flocking and schooling.

**Engineering**
- Robot swarming.
- Programmed colloidal self-assembly.
- Genetic engineering of pattern-forming cells (synthetic biology).
- Pattern formation in traffic.

As it is not possible to study in details all these topics in class, a selection of particularly well-established cases will be developed in more detail during the course. Besides the topics covered in class, each student will choose a specific problem of interest (from the suggested topics above or not, but related to the main course theme) the topic choice needs to be approved by Prof. Campàs) and do a short research assignment, consisting in reading selected materials on the topic and solving a specific short problem related to the topic of interest. Each student will work with Prof. Campàs, who will provide reading materials and short problems on the specific topic chosen. The last week of the course, each student will be expected to provide a short (2-4 pages) synopsis of the chosen problem and give a presentation to the other students in the class.

**Syllabus**

Syllabus (continued)


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Lecture format

- Each lecture will have one of two possible formats:

  - **Literature days.** The goal of the literature class days is to discuss a specific research article and to investigate, as a group, the conceptual idea, its implications, its applications, its analysis and alternative approaches. On each of these lectures we will discuss one or two research articles. On Thursdays every week, one student will present (15-20 min. oral presentation) one of the assigned papers. After the presentation, we will have a group discussion on the subject. Each student will have to present only one paper in the entire course. Everyone in class must read and submit a short review on the paper the night before the lecture.

  - **Conventional lecture.** In these lectures, Prof. Campàs will teach either necessary background to follow the assigned reading materials or discuss a particular topic in more detail.

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Assignments

- There will be three kind of assignments during the course:

  - **Read and review assigned reading materials.** Everyone in class must read and submit a short review on the paper assigned the night before the lecture in which that material will be covered (only for 'literature' type lectures).

  - **Paper presentation.** Every week, one student will present (15-20 min. oral presentation) one of the assigned papers. Each student will have to present only one paper in the entire course. The first week of class we will decide who presents each of the assigned reading materials.

  - **Short research assignment (Final project).** Each student will choose a specific problem of interest (from the suggested topics above or not, but related to the main course theme - the topic choice needs to be approved by Prof. Campàs) and do a short research assignment, consisting in reading selected materials on the topic and solving a specific short problem related to the topic of interest. The student will work with Prof. Campàs, who will provide reading materials and short problems on the specific topic chosen. The last week of the course, each student will be expected to provide a short (2-4 pages) synopsis of the chosen problem and give a presentation to the other students in the class.

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Evaluation

- The course will be evaluated based on i) homework assignments (paper reviews and presentation 30%), ii) a research assignment (final project) on a chosen topic related to the course theme (50%) and iii) a class presentation of the final project (20%). Each missed class (for unjustifiable reasons) will lower the final grade by 5%.
Reading assignments


- **Reading 1b:** M. Cross and H. Greenside. *Pattern Formation and Dynamics in Non-equilibrium systems*, (Cambridge University press). Read Introduction chapter (only pages 1 to 38).


MATRL 272/BMSE 272
Mechanical Force and Biomolecules

Omar A. Saleh
March 31, 2019

Summary In this course, we will explore the field of single-molecule biophysics, and in particular the role of mechanical force in biomolecular behavior. Mechanical forces are critical to a wide range of biological processes, and modern techniques allow the experimentalist to study those processes by directly measuring forces generated by biomolecules and/or perturbing the system with an applied force. The course will start off with an introduction to the experimental techniques used to apply force to single biomolecules (e.g. optical/magnetic traps, AFM, etc.), with a focus on quantitative calibration approaches. The remainder of the course will cover various aspects of the molecular biophysics of mechanical force, including the linear elasticity of biomolecules; DNA torsional mechanics and topology (twist, writhe); force-induced unfolding and unzipping transitions; and force-generation by motor proteins. Stochastic physical models of molecular behavior (e.g. Langevin, Kramers) will be a theme throughout. The course will draw on recent literature, culminating with student presentations of recently-published papers from the field.

A detailed lecture schedule is on the last page.

Instructor Omar A. Saleh: saleh@ucsb.edu; x8814; BioE 3006. Office hours will be flexible, or scheduled, depending on enrollment.

Lectures Monday and Wednesday, 3:30–4:45pm, 1335 Eng II. Regular lectures will be canceled on May 15 due to my travel schedule. May 27 is a holiday. Depending on enrollment, we might meet during final exam week to finish the student presentations.

Website The course will be available on GauchoSpace. Lecture notes, slides, and articles will be posted on the website.

Evaluation will be based on two short, online quizzes; two problem sets; and a single end-of-quarter presentation based on an article from the recent literature. The quizzes will take place on GauchoSpace, problem sets will be handed in. For the presentation: I will provide the class with a list of papers to choose from, and briefly describe each during lecture. With my approval,
students can elect to present a paper of their own choosing. The presentations will take place over the last two weeks of the quarter, possibly including the final exam period.

**Prerequisites** Students will should be familiar with the basic principles of statistical mechanics, and the basics of biomolecular structure.

**Useful textbooks** No textbook is required, but here’s a list of good books that are relevant for various parts of the class:

<table>
<thead>
<tr>
<th>Subject</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein Structure</td>
<td>Branden and Tooze, “Introduction to Protein Structure”; Creighton, “Proteins”</td>
</tr>
<tr>
<td>Intermolecular forces</td>
<td>Israelachvili, “Intermolecular &amp; Surface Forces”</td>
</tr>
<tr>
<td>Binding interactions</td>
<td>Klotz, “Ligand-receptor Energetics”</td>
</tr>
<tr>
<td>Molecular biophysics</td>
<td>Daune, “Molecular Biophysics”; Cantor and Schimmel, “Biophysical chemistry”</td>
</tr>
</tbody>
</table>

**Detailed lecture Schedule** follows on the last page.
<table>
<thead>
<tr>
<th>Day</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mon 4/1</td>
<td>Motivation and intro to biomolecular context of force; practical matters; start Techniques</td>
</tr>
<tr>
<td>Wed 4/3</td>
<td>Techniques to manipulate single-molecules: Overview of optical and magnetic traps; AFM; etc.</td>
</tr>
<tr>
<td>Mon 4/8</td>
<td>Techniques: First half Finish experimental geometries; Second half Measurement theory (Langevin dynamics)</td>
</tr>
<tr>
<td>Mon 4/15</td>
<td>Elasticity: Linear elasticity of biomolecules (bend, twist, stretch)</td>
</tr>
<tr>
<td>Mon 4/22</td>
<td>Elasticity: Twist: the topology and biological role of twisted double-stranded DNA</td>
</tr>
<tr>
<td>Wed 4/24</td>
<td>Elasticity: Twist: Measuring and manipulating super-coiled DNA</td>
</tr>
<tr>
<td>Mon 4/29</td>
<td>Transitions: The free energy surface and its relation to (bio)chemical rates; Arrhenius and Kramers theories</td>
</tr>
<tr>
<td>Wed 5/1</td>
<td>Transitions: The effect of force; Bell/Evans Theory; Beyond Bell; constant force and constant rate msmts</td>
</tr>
<tr>
<td>Mon 5/6</td>
<td>Transitions: Dudko/Hummer/Szabo, catch bonds, high-speed measurements</td>
</tr>
<tr>
<td>Wed 5/8</td>
<td>Transitions: Non-eqlbm thermodynamics (fluctuation theorems; Jarzynski and Crooks)</td>
</tr>
<tr>
<td>Mon 5/13</td>
<td>Molecular motors: The Brownian ratchet; futile cycles; flash ratchets; energy sources</td>
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<tr>
<td>Wed 5/15</td>
<td>No lecture; Omar out of town</td>
</tr>
<tr>
<td>Fri 5/17</td>
<td>MAKEUP LECTURE (TBD): Molecular motors: Case study: kinesin</td>
</tr>
<tr>
<td>Mon 5/20</td>
<td>Molecular motors: The motor zoo; Case study: F0/F1 ATPase</td>
</tr>
<tr>
<td>Wed 5/22</td>
<td>Molecular motors: Stochasticity and shot noise</td>
</tr>
<tr>
<td>Mon 5/27</td>
<td>No lecture: Memorial Day</td>
</tr>
<tr>
<td>Wed 5/29</td>
<td>Student presentations</td>
</tr>
<tr>
<td>Mon 6/3</td>
<td>Student presentations</td>
</tr>
<tr>
<td>Wed 6/5</td>
<td>Student presentations</td>
</tr>
<tr>
<td>6/10-12</td>
<td>Student presentations during final exam period; TBD</td>
</tr>
</tbody>
</table>
Haptics
From the Human Sense of Touch, to Emerging Haptic Technologies and Applications

https://goo.gl/hW5BNw

Course ID:
MAT 594H (S/T in MAT)
ECE 594T (S/T Robotics)
ECE 194 (S/T Robotics & Control)

Class Location: Elings 2003
Time: 2-3:15pm
Lab Time: TBA

Instructor: Yon Visell
Department of Electrical and Computer Engineering
Media Arts and Technology Program
Department of Mechanical Engineering (by courtesy)
Office: Elings 2213
Office Hours: Tuesday 330-430pm and Wednesday 3-4pm.
Research Lab: www.re-touch-lab.com
Email: yonvisell@ucsb.edu
TA: TBA

Prerequisites: No specific prerequisites. Open to students in Engineering or by permission of instructor.
Required Texts: Articles; PDF documents provided by instructor. Selected texts:
goo.gl/yfMY81

Other Recommended Texts:
M. Lin, M. Otaduy, Haptic Rendering, CRC Press, 2008
L. Jones, Haptics. MIT Press, 2018. (Written for a non-academic audience.)

Exploring Haptic Perception, Engineering, Applications

Haptics refers to science and engineering related to the sense of touch. The course introduces human haptics, including anatomy, physiology, and perception for the tactile system. It presents aspects of the engineering of electronic technologies for addressing the sense of touch, and applications for the design of haptic systems for human-computer interaction, sensory substitution, virtual reality, and other creative areas. The class combines readings, hands-on activities, lectures, discussion, and projects.

Projects developed in the course have led to successful M.S. projects and Ph.D. topics.

Haptics is a rapidly evolving field, and this course offers us the opportunity to engage with current research through articles, lectures, videos – and our own experiments.

Overview of Contents
1. **Introduction**: Human touch sensing and interaction, Electronic technologies, Synthesis techniques for haptics, Applications. Course summary.

2. **Human Haptics**: Perception, Movement, and Related topics.


5. **Course Mini Projects**

**Activities and Assessments**

Short written assignments (1-2): 10 points each  
Mini-projects (2-3): 25 points each  
Open project (of your choosing): 25 points  
Attendance and participation: 20 points (1 point / class)  
Paper Presentations (Optional): 10 points

**Graduate students** enrolled in the course are also required to present a paper in class from the haptics literature. Presentations should be about 30 minutes, and should provide broader context for the paper. Depending on enrollment, this will be done individually or in pairs. Slides are due one class in advance.

**UCSB policies** on Academic Integrity and Academic procedures apply to this course. You may not copy one anothers’ coursework. You may not use software codes or written material without attribution. All of these are considered cheating and will be dealt with in accordance with UCSB policies on Academic Integrity. Changes to the parameters of the course may need to be made during the quarter. In the case of such events, students will be notified by the instructor through their official UCSB e-mail.
Introductory Bioelectronics
Instructor: Luke Theogarajan

1. Basic Chemical & Biochemical Concepts
2. Cells and their basic building blocks
3. Basic Biophysical Concepts & Methods
4. Spectroscopic Techniques
5. Electrochemical Principles & Electrode Reactions
6. Biosensors
7. Basic Sensor Instrumentation and Electrochemical Sensor Interfaces
8. Instrumentation for Other sensor Technologies
9. Microfluidics: Basic Physics & Concepts
10. Microfluidics: Dimensional Analysis and Scaling

Text: Introductory Bioelectronics: For Engineers and Physical Scientists 1st Edition
by Ronald R. Pethig, Stewart Smith
Soft Matter Physics
Instructors: Cristina Marchetti and Zvonimir Dogic

Course Description:
The physics of soft condensed matter involves materials that are easily deformable by externally applied stresses, by electric or magnetic fields, or simply by fluctuations (of thermal or other origin). In this course we will use a physics-based approach to study the structure, assembly and dynamical properties of a variety of soft materials, such as simple and complex fluids, colloidal systems, liquid crystals, polymers, granular matter and gels, including biological examples. Topics covered will include elasticity, viscosity and viscoelasticity, capillarity and wetting, phases and phase diagrams of soft materials, entropy-driven phase transitions, Brownian motion and active matter. The level is appropriate for final year undergraduate students in physics. The course may also be of interest to first year graduate students in physics and final year undergraduates or first year graduate students in chemistry, materials science, and chemical engineering.
University of California, Santa Barbara
College of Engineering

Mechanical Engineering

ME 128 Design of Biomedical Devices
Fall Quarter 2019

Lecturer: Steve Laguette
CLASS: MWF 12:00 to 12:50 pm
CLASSROOM: Engr II, rm 2243

OFFICE HRS: M/W 11- noon and by appointment
E-MAIL: laguette@engineering.ucsb.edu

TA : Matt Devlin (mrdevlin6@gmail.com)
office hrs: TBD

Course Description
Introductory course addresses the challenges of biomedical device design, prototyping and testing, material considerations, regulatory requirements, design control, human factors and ethics.

Course Prerequisite
ME 10, ME 14, ME 15 & ME 16

Text, Reference
King, P.H. and R.C. Fries, Design of Biomedical Devices and Systems, Marcel Dekker, 2003

Course Objectives
The course objectives are (1) to introduce students to the biomedical device industry, (2) introduction to biomedical design from concept to market, (3) design problem solving, creative thinking, design control, project planning and teamwork and (4) insight into human factors and ethical challenges.

Topics Covered
1. Engineering Design and Medical Devices
2. Need Identification
3. Human Factors, Anatomy and Physiology
4. Design Specifications
5. Regulatory Requirements and Quality System Regulations
6. Biomaterials and Materials Selection
7. Design Control

Rev 092019
Bio-inspired design in fluids – 1 quarter long
Instructor — Emilie Dressaire

Course Description:
In this course, students will learn how Nature can support the creative design process. Students will study evolutionary adaptation as a source for inspiration, extracting design principles to leverage the functionality, adaptability and robustness of biological systems. To advance student knowledge of biological strategies and facilitate quantitative analysis of the proposed solutions, the course focuses on biologically inspired design in fluids. Over the quarter, the students will learn how biological systems deal with fluids and the bio-inspired design process. The course includes lectures, case studies and hands-on design activities. Final projects will involve a team of students. Each team will select a biological system from our local zoo and define a design problem it solves. The students will then expand their search to learn about relevant biological systems. Students will (1) identify the design principles used by the biological system(s) (2) propose a bio inspired design to achieve the identified function, (3) produce a demo of the design principle and prepare a pamphlet describing their work to a general audience.

Learning Objectives:

- Outcome 1: Students will gain a fundamental understanding of how biological systems live in and use moving fluids.
- Outcome 2: Students will learn how biological systems can inspire and support engineering design. Students will gain basic understanding of Nature's design principles. They will also use several methods to incorporate one or multiple biologically design options into their design process. The importance of biodiversity will be stressed.
- Outcome 3: Student’s ability to work as a team and communicate (at technical and non-technical levels) will be enhanced.

Lecture and design activities

Textbooks: Steven Vogel, Life in Moving Fluids, Princeton Paperbacks, 1994

Prerequisites: An undergraduate level course in fluid mechanics
**Computational methods, instrumentation & logic to quantify behavior**

Instructor — **Matthieu Louis**

**Course number:** TBD (to be cross-listed with MCDB, BMSE and DYNS)

**Course description:** The main purpose of this class is to teach grad students the basic techniques and logic behind the design of experiments to quantify behavioral responses through automated tracking and closed-loop stimulations. The first objective is to **present the principles of computer vision** to identify and to track an object of interest in a sequence of images (movie). Although the methodology will be illustrated on the movement of small animals such as fruit flies (*Drosophila*), the methodology will be relevant to the tracking of cells in a static background. The class will propose a step by step introduction to an existing Python software (www.pivr.org) that permits on-line tracking and light stimulations. The second objective of the class is to **familiarize the students with the instrumentation** (tinkering) to build an affordable tracking system that includes a CCD camera combined with a LED system for background illumination. This introduction will include 3D printing and the building of simple electronic circuits. The image analysis and closed-loop light stimulation will be implemented by a Raspberry PI computer. The third objective of the class will be to **conduct and analyze a series of hypothesis-driven experiments** with *Drosophila* at the adult or the larval stage. The experimental tests will focus on the analysis of orientation behavior in response to light (phototaxis) and chemical stimuli (chemotaxis). Students will learn how to design a protocol to test the validity of models related to the conversion of sensory stimuli into orientation responses. Upon recording the behavior of *Drosophila*, they will write custom scripts to extract “kinematic” variables from the movies, and to perform correlative analyses between the time series of the sensory stimuli and the behavioral output.

**Extension & cross-training:** In the long term, this course could be co-taught to include two parallel tracks centered on the tracking of (i) moving cells (with Max Wilson and/or Sebastian Streichan) and (ii) small animals (*Drosophila* and *C. elegans*). Although students will pick the track that best matches their interest for graduate research, the entire class will meet on a weekly basis for core teaching and to discuss solutions to similar problems involving object tracking and closed-loop stimulations. The class will be opened to graduate students with a biology and an engineering background. By pairing students with different expertise, we will promote cross-training. While bioengineers might be more comfortable with the computer-vision and instrumentation aspects of the class, knowledge in basic neuroscience might help biologists lead the execution of behavioral experiments.

**Learning objectives:**

- Computer vision: identifying and tracking an object in a static background
  - Tracking of a single moving object
- Basic instrumentation: building a closed-loop tracker
  - Design of an affordable imaging setup based on Raspberry PI
- 3D printing of parts
- Soldering of electronic circuits to engineer an infrared backlight
- Benchmarking of a new tool: validating the tracker’s performance
- Designing behavioral experiments
  - Experimental strategy to test hypotheses about the control of orientation behavior
  - Design of statistical procedures to analyze the expected results (minimal sample sizes)
- Conducting experiments involving small animals: Drosophila larvae and adults
  - Rearing flies (and any other animals used in the experiments)
  - Identifying and controlling key factors susceptible of affecting behavior (manipulation, external light condition, internal state related to starvation, etc.)
  - Testing orientation elicited by light and chemical stimulations (gradients)
- Data analysis
  - Developing scripts to quantify behavioral variables and to test input-output relationships
  - Visualizing the data produced during the class
- Interpretation of the results
  - Discussing the validity of the initial hypotheses
  - Brainstorming about a possible set of future experiments to improve the analysis
- Presentation of the results in group

**Prerequisite:** Prior exposure and basic knowledge of Python and/or Matlab programming.

**Note:** This class will be based on the PiVR tracker developed by the Louis lab (www.pivr.org). PiVR was used for teaching purposes at the Cold Spring Harbor Laboratory summer school for Drosophila Neurobiology (2016-2019) as well as at the 2018 KITP summer school on Sensory Navigation.
CS-291I: Bionic Vision
Instructor — Michael Beyeler
Lecture only

Course Description:
What would the world look like with a bionic eye?
This graduate course will introduce students to the multidisciplinary field of bionic vision, with an emphasis on both the computer science and neuroscience of the field. The course will give an overview of current bionic eye technology designed to restore vision to people living with incurable blindness. Students will be exposed to the neuroscience of the human visual system, key engineering concepts for designing a brain-computer interface, and computational principles underlying the encoding of a visual scene into an artificial stimulus that the brain can interpret. We will cover recent advances in theory and applications, and discuss outstanding challenges with existing devices. The course will conclude with a programming project (teams of ≤ 3, any language/environment ok) in lieu of a final exam, giving students an opportunity to gain hands-on experience of working on open research problems using methods and tools best suited to their scientific background.

Course Objectives:
The course will give an overview of current bionic eye technology designed to restore vision to people living with incurable blindness. By the end of the course, students should be able to:

• Identify various types of bionic eye technologies, their differences and similarities
• Have a basic understanding of the neuroscience of the human visual system
• Be familiar with common preprocessing, encoding, and electrical stimulation methods
• Understand the limitations of current bionic eye technologies
• Have hands-on experience of working on open problems in the field

The course is targeted to a diverse audience spanning from computer science (human factors, neural networks, computer vision) to psychology (vision, psychophysics) and brain sciences (computational neuroscience, neuroengineering).

Prerequisites:
There are no official prerequisites for this course. The instructor will do his best to make the course content self-contained. However, prior programming experience (e.g., Python, Matlab, C++) will be highly beneficial as Homework 2 (HW2) and the final project require programming. Students will be introduced to pulse2percept, a Python-based simulation framework for bionic vision, which will form the basis for HW2 and (optionally) the final project.
8. Patents and Intellectual Property  
9. Manufacturing and Quality Control  
10. Animal Testing, Clinical Studies, and Ethical Consideration

Credit units of class/laboratory schedule
3 units of lecture (3 hr/week) with additional design efforts (3 hr/wk)

Course Assignments
1. Weekly reading assignments, Homework assignments (20%)  
2. Lecture Quizzes (20%)  
3. Team Case Study Benchmark Design Engineering Report (30%)  
   Working in teams, the students must identify and select a commercially available medical  
   device as a benchmark for review. The students should prepare a 10 to 15 page technical  
   engineering report. The students should review and discuss the benchmark device within  
   the framework of the course topics including:  
   - Need Identification and Problem Definition  
   - Anatomy and Physiology  
   - Patents and Intellectual Property  
   - Performance Requirements  
   - Regulatory Requirements  
   - Biomaterials and Materials Considerations  
4. Team Case Study Design Review Presentation (30%)  
   Working in teams, the students should propose the design and fabrication of a medical  
   device with “improved” performance characteristics as compared with the benchmark  
   design. The students should prepare and deliver a Design Review presentation and  
   discuss the following:  
   - Technical Considerations  
   - Design Considerations including Patents and IP  
   - Proposed Efforts and Activities including Regulatory Requirements  
   - Proposed schedule/critical path including Clinical Studies and Quality  
     System Requirements

- If you are a student with a disability and would like to discuss special academic  
  accommodations, please feel free to contact me at your convenience.  
- You are expected to attend all lectures. Absences will be noted and will negatively affect  
  your grade.  
- Your grade is determined by achievement and results.  
- Homework problems are expected to be completed as an individual not in collaboration  
  with others.  
- Homework is typically due on Fridays at the start of lecture class.  
- Treat all exams and quizzes as work to be conducted privately  
- Maintain personal academic integrity in accordance with the College of Engineering  
  Policy on Academic Conduct.  
- There will be no make-up for homework, quizzes or exams unless medical note or prior  
  approval of the instructor.
Professional Component
3 units of engineering topic

Program Outcomes
1. The student should acquire the experience of working as part of a team to solve a practical design problem.
2. The student should be aware that an engineer often faces ethical issues and should know that the engineer has a responsibility to work within ethical principles.

Relationship to Program Objectives
1. The student gains experience in applying principles of mathematics, science and engineering to solve problems.
2. The student is required to demonstrate the ability to understand and design a useful product in the context of solving a design problem.
3. The student is required to work effectively as part of a team.
4. The student is required to effectively communicate a design

Prepared by: Stephen W. Laguette
Date: September 20, 2019
# Course Schedule and Assignments

<table>
<thead>
<tr>
<th>Day/Date</th>
<th>Topic/Activity</th>
<th>Task to be completed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Week 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F 9/27</td>
<td>Introduction/Course Objectives</td>
<td></td>
</tr>
<tr>
<td><strong>Week 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M 9/30</td>
<td>Medical Device Industry</td>
<td></td>
</tr>
<tr>
<td>W 10/2</td>
<td>Medical Device Industry</td>
<td></td>
</tr>
<tr>
<td>F 10/4</td>
<td>Need Identification</td>
<td>Chap 1, 2 Form Teams</td>
</tr>
<tr>
<td><strong>Week 3</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M 10/7</td>
<td>Anatomy and Physiology</td>
<td>Chap 3, 4 HW#1 Due</td>
</tr>
<tr>
<td>W 10/9</td>
<td>Product Documentation</td>
<td></td>
</tr>
<tr>
<td>F 10/11</td>
<td><em>Ophthalmology</em></td>
<td>HW#1 Due Select Benchmark Design</td>
</tr>
<tr>
<td><strong>Week 4</strong></td>
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<tr>
<td>M 10/14</td>
<td>Benchmark Report and Design Review</td>
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<td>W 10/16</td>
<td>Biomaterials and Material Selection</td>
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<td>F 10/18</td>
<td>Boston Scientific – Patrick Marek</td>
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<tr>
<td>M 10/21</td>
<td>Overview FDA Regulations</td>
<td>Chap 13, 14 HW#2 Due</td>
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<tr>
<td>W 10/23</td>
<td>Regulatory Requirements/ Quiz #1</td>
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<tr>
<td>F 10/25</td>
<td>Arthrex – John Batikian</td>
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<tr>
<td>M 10/28</td>
<td>Quality System Regulation</td>
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<tr>
<td>W 10/30</td>
<td>Design Control</td>
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<tr>
<td>F 11/1</td>
<td>Medtronic Diabetes – Sarnath Chattaraj, PhD</td>
<td>Chap 12</td>
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<td>All teams meet with instructor to review progress</td>
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<tr>
<td>M 11/4</td>
<td>Prototyping and Testing</td>
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<tr>
<td>W 11/6</td>
<td>Human Factors in Design</td>
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<td>F 11/8</td>
<td>Sansum Diabetes – Jordan Pinsker, MD</td>
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Rev 092019
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<tr>
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<td>Human Clinical Studies</td>
<td>Chap 21</td>
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<td>Manufacturing Systems / <strong>Quiz#2</strong></td>
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<td><em>Cottage Hospital IRB - Laura Isaacs</em></td>
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<td>Week 10</td>
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<tr>
<td>M 11/25</td>
<td>Projects Review</td>
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<td>W 11/27</td>
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<tr>
<td>Week 11</td>
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<tr>
<td>M 12/2</td>
<td><em>(Workshop - Work on Design Project)</em></td>
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<tr>
<td>W 12/4</td>
<td><strong>Team Design Review Presentations</strong></td>
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<td>Engr II, rm 2243</td>
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<tr>
<td>F 12/6</td>
<td><em>(No Lecture)</em></td>
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BioEXXX: Industrial Internship Experience: This internship will be designed to integrate academic studies through real-world practical applications in the workplace. By participating in the program, students can complete their degree while building their skills and resumes with relevant work experience. Student will be able to explore specific interests within their academic discipline and refine their post-graduation goals.
Appendix G: Degree Sheets for M.S. and Ph.D. in Biological Engineering
In addition to departmental requirements, candidates for graduate degrees must fulfill University requirements described in the “Graduate Education” section of the UCSB General Catalog.

During the first year of study students are required to develop a formal study plan, which must be approved, by the student’s faculty advisor and the department graduate advisor. In this plan, students select a major area of study from among the 3 fields offered by the Program.

A total of 36.0 quarter units of coursework are required for the M.S. Plan I (Thesis): 11 units for letter grade in Core courses; A minimum of 12 units for letter grade in four additional courses with at least two drawn from one focus area, at least one from a different focus area, and one additional science or engineering elective, 6 units of graduate seminar, and 3 units of Lab Rotation and completion of a thesis.

In addition, all students will choose to a) take an existing course in biomedical/pharmaceutical devices and translation (3 units), or b) complete an industry internship (3 units), or c) participate in approved activities that provide exposure to industry and translational applications of Biological Engineering (3 units) (e.g., Biomedical Engineering Society student chapter tours, biotechnology industry showcase, internships). If students choose the latter, the proposed program of activities will be approved by the Graduate Coordinator.

Time-to-degree for MS is 3 years. These courses must be passed with a grade of C or better, and students are expected to maintain a GPA of at least 3.0

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<td>BIOEXXX</td>
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<tr>
<td>BIOE596</td>
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<td>BIOEXXX</td>
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<th>FOCUS AREAS</th>
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<th>CHOOSE 2 COURSES FROM 1 FOCUS AREA, 1 COURSE FROM A SECOND AREA AND 1 ELECTIVE (12.0 units total)</th>
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<tr>
<td>MCDB172</td>
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<tr>
<td>BIOEXXX</td>
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| FOCUS AREA 2: COMPUTATIONAL, SYNTHETIC AND SYSTEMS BIOLOGY |

<p>| COURSE #   | COURSE NAME                                      | QUARTER | UNITS | GRADE |
| PHYS250    | Physics of Living Matter                         |         | 3.0   |       |
| BMSE219    | Basic Microscopy for Quantitative Biology        |         | 3.0   |       |
| ECE594     | Optics and Imaging                               |         | 3.0   |       |
| ECE594     | Neuroengineering – measuring and manipulating activity | | 3.0   |       |
| MCDB172    | Biological Dynamics                              |         | 3.0   |       |
| BIOEXXX    | Applied Machine Learning/Big Data                |         | 3.0   |       |
| BIOEXXX    | Signal Processing in Biology                     |         | 3.0   |       |</p>
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<tr>
<th>COURSE #</th>
<th>COURSE NAME</th>
<th>QUARTER</th>
<th>UNITS</th>
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<td>Engineering Approaches to Systems Biology</td>
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<td>3.0</td>
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<td>Omics Enabled Biotechnology</td>
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<td>3.0</td>
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<td>CHE174</td>
<td>Model-Guided Engineering of Biological Systems</td>
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<td>3.0</td>
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<td>Bioinformatics/Genomics</td>
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<td>Molecular Engineering</td>
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<td>I/O Hacking Biology</td>
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<td>Synthetic Biological Design, Control and Computing</td>
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<td>3.0</td>
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<tr>
<td>CS211B</td>
<td>Numerical Simulation (in Biology)</td>
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**FOCUS AREA 3: CELL, TISSUE AND DEVICE MECHANICS AND ENGINEERING**

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<td>Engineering Biomaterials</td>
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<td>ME225BP</td>
<td>Methods in Mechanobiology and Biofabrication</td>
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<td>3.0</td>
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<tr>
<td>BIOEXXX</td>
<td>Structure and Function of Biological Materials</td>
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<td>3.0</td>
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<td>BIOEXXX</td>
<td>Cell and Tissue Engineering</td>
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<td>ME225OC</td>
<td>Pattern Formation &amp; Self-Organization</td>
<td></td>
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<tr>
<td>BIOEXXX</td>
<td>Physics and Mechanics of Multicellular Systems</td>
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**APPROVED SCIENCE AND ENGINEERING ELECTIVES**

Students must also take an additional **3.0 letter graded units** of science and engineering electives approved by the Graduate Coordinator

<table>
<thead>
<tr>
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<td>Haptics</td>
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<td>ECEXXX</td>
<td>Introductory Bioelectronics</td>
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<tr>
<td>PHYSXXX</td>
<td>Soft Matter Physics</td>
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<tr>
<td>MEXXX</td>
<td>Bio-inspired design</td>
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<tr>
<td>MCDBXXX</td>
<td>Computational methods in behavior</td>
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<td>CS291I</td>
<td>Bionic Vision</td>
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**ADDITIONAL REQUIREMENTS**

All students will choose to a) take an existing course in biomedical/pharmaceutical devices and translation (3 units), or b) complete an industry internship, or c) participate in approved activities that provide exposure to industry and translational applications of Biological Engineering (e.g., Biomedical Engineering Society student chapter tours, biotechnology industry showcase, internships). If students choose the latter, the proposed program of activities will be approved by the Graduate Coordinator

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Gr ADUATE SEMINAR (6.0 units total)

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Thesis

All students are expected to write and defend an original M.S. thesis. Following successful submission of the thesis, the student undergoes a thesis defense. Required coursework must be completed by the end of the quarter in which the thesis is submitted. The student’s Master’s Committee supervises the thesis research, administers the thesis defense, and certifies the completion of required coursework.

M.S. Committee:

Chair: _______________________________
Member: ______________________________
Member: ______________________________
Member: ______________________________

M.S. DEGREE REQUIREMENTS SATISFIED: ____________________________  Quarter/Year
Doctor of Philosophy – Biological Engineering

In addition to departmental requirements, candidates for graduate degrees must fulfill University requirements described in the “Graduate Education” section of the UCSB General Catalog.

During the first year of study students are required to develop a formal study plan, which must be approved, by the student’s faculty advisor and the department graduate advisor. In this plan, students select a major area of study from among the 3 fields offered by the Program.

Ph.D. students must complete a minimum of 36.0 quarter units of coursework: 11 units for letter grade in Core courses; A minimum of 12 units for letter grade in four additional courses with at least two drawn from one focus area, at least one from a second focus area, and one additional science or engineering elective, 6 units of graduate seminar, and 3 units of Lab Rotation.

In addition, all students will choose to a) take an existing course in biomedical/pharmaceutical devices and translation (3 units), or b) complete an industry internship (3 units), or c) participate in approved activities that provide exposure to industry and translational applications of Biological Engineering (3 units) (e.g., Biomedical Engineering Society student chapter tours, biotechnology industry showcase, internships). If students choose the latter, the proposed program of activities will be approved by the Graduate Coordinator.

Students who enter the program with a Master’s degree from a comparable department or program at another institution may receive subject credit, as approved by the graduate advisor. The department requires that students maintain a minimum grade-point-average of 3.5 in the Core courses and Focus Area courses. Time-to-degree: 3 years to advance to candidacy, 6 years to complete the Ph.D.

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FOCUS AREAS

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<td>Neuroengineering – measuring and manipulating activity</td>
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<td>Biological Dynamics</td>
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### FOCUS AREA 2: COMPUTATIONAL, SYNTHETIC AND SYSTEMS BIOLOGY

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<tr>
<td>BIOEXXX</td>
<td>Molecular Engineering</td>
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### FOCUS AREA 3: CELL, TISSUE AND DEVICE MECHANICS AND ENGINEERING

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<td>ME225BP</td>
<td>Methods in Mechanobiology and Biofabrication</td>
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<td>BIOEXXX</td>
<td>Structure and Function of Biological Materials</td>
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<td>Physics and Mechanics of Multicellular Systems</td>
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Students must also take an additional **3.0 letter graded units** of science and engineering electives approved by the Graduate Coordinator

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<td>ECEXXX</td>
<td>Introductory Bioelectronics</td>
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<td>3.0</td>
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</tr>
<tr>
<td>PHYSXXX</td>
<td>Soft Matter Physics</td>
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<td>3.0</td>
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<tr>
<td>MEXXX</td>
<td>Bio-inspired design</td>
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<tr>
<td>MCDBXXX</td>
<td>Computational methods in behavior</td>
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</tr>
<tr>
<td>CS291I</td>
<td>Bionic Vision</td>
<td></td>
<td>3.0</td>
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</table>

### ADDITIONAL REQUIREMENTS

All students will choose to a) take an existing course in biomedical/pharmaceutical devices and translation (3 units), or b) complete an industry internship, or c) participate in approved activities that provide exposure to industry and translational applications of Biological Engineering (e.g., Biomedical Engineering Society student chapter tours, biotechnology industry showcase, internships). If students choose the latter, the proposed program of activities will be approved by the Graduate Coordinator

<table>
<thead>
<tr>
<th>COURSE #</th>
<th>COURSE NAME</th>
<th>QUARTER</th>
<th>UNITS</th>
<th>GRADE</th>
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<tbody>
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<td></td>
<td>Approved Biological Engineering Activities</td>
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GRADUATE SEMINAR (6.0 units total)

<table>
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<td></td>
<td>Professional Seminar</td>
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ADVANCEMENT TO CANDIDACY EXAM

The PhD qualifying process will include a Dissertation Proposal Presentation, which will serve as an Oral Qualifying Exam. This will consist of a written thesis proposal, an oral defense of this proposal, and an oral examination by the pre-candidacy thesis committee. This committee is comprised of at least four academic senate faculty members: a chair, who is selected from among the Program faculty by the Graduate Advisor, and three or more faculty members selected by the student, at least one of whom is a member of the Program faculty. Upon successful completion of this examination, students advance to candidacy.

Chair: ____________________________
Member: __________________________
Member: __________________________
Member: __________________________

Exam passed on (date): ________________

DISSERTATION

A written dissertation is required, which must demonstrate the student’s ability to contribute significantly and independently to the field. This will be guided by a dissertation committee comprised of at least four academic senate faculty members, at least two of who are members of the Program. This nominally consists of the members (but not the chair) of the qualifying exam committee plus the student’s thesis advisor, who serves as chair of this committee. Candidates must complete the dissertation and pass a public thesis defense consisting of presenting a seminar talk and answering questions posed by the dissertation committee.

Doctoral Committee:   Chair: ____________________________
                      Member: ____________________________
                      Member: ____________________________
                      Member: ____________________________

Dissertation Defense passed on: ________________ Month/Day/Year
Appendix H: Budget

Attached are two budgets. The first reflects additional expenses above and beyond the current operating budget of the campus. I.e., the first budget does not include the salaries of current UCSB faculty or salaries of the Center for Bioengineering staff who will be transferred to the new Program, nor their fringe benefits. It also excludes the TA lines currently assigned to the graduate bioengineering emphasis, which will also be subsumed by the new Program. The second budget presents the total, combined cost of the proposed graduate Program, the graduate emphasis, and the Center for Bioengineering. This includes existing faculty and staff salary and benefit lines.
### Biological Engineering PhD Program Budget

<table>
<thead>
<tr>
<th>FACULTY</th>
<th>MONTHS</th>
<th>% TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 NEW FACULTY MEMBERS (1) NEW FT/YEAR</td>
<td>9</td>
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<tr>
<td>AVERAGE STARTING SALARY $120K/yr</td>
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#### FACULTY SALARIES SUBTOTAL
$120,000

### INSTRUCTIONAL SUPPORT

<table>
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<tr>
<th>TRAVEL</th>
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<td>IT support</td>
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<tr>
<td>Computer workstations 6@$2500</td>
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</tr>
<tr>
<td>Telephone charges</td>
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<td>Print materials and program marketing</td>
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<tr>
<td>Newsletters and online</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instructional supplies, books, lab supplies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Furniture 2 offices @$5000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shared Microscope</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biotechnology Industry Showcase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recruitmen Events, orientation, student admittance day</td>
<td></td>
<td></td>
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<tr>
<td>COC meeting at AIMBE</td>
<td></td>
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</tr>
<tr>
<td>Council of Chairs Dues for Director and Assoc. Director</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIC Reception at BMES Annual Meeting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Booth at BMES Annual Meeting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student travel awards to BMES (3 students)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel to BMES Annual Meeting (2 Faculty, 2 staff)</td>
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#### TA SALARIES SUBTOTAL
$67,648

#### STAFF

<table>
<thead>
<tr>
<th>EVENTS ASSISTANT, BLANK ASST 3 (NEW POSITION)</th>
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<th>% TIME</th>
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<tr>
<td>ACADEMIC PERSONNEL/PAYROLL ANALYST, ADMIN OFFCR 2 (NEW POSITION)</td>
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<td></td>
</tr>
<tr>
<td>$0.00</td>
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<tr>
<td>$0.00</td>
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<tr>
<td>$0.00</td>
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#### STAFF SALARIES SUBTOTAL
$121,370

### FRINGE BENEFITS

<table>
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<th>TRAVEL TOTAL</th>
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<tr>
<td>Travel Student Travel Awards (Conference/Presentations)</td>
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<td>Travel awards for BMES Symposium (1 student, 1 Faculty, 1 staff)</td>
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#### BMES

<table>
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<tr>
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<tr>
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<td>Student travel awards to BMES (5 students)</td>
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#### EVENTS

<table>
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<td>Rent event-rooms, orientation, student admittance day</td>
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#### EQUIPMENT

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<tr>
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<tr>
<td>Shared Microscope</td>
<td>$350,000</td>
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<td>Furniture 2 offices ($5000)</td>
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<td>EQUIPMENT TOTAL</td>
<td>$360,000</td>
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### INSTRUCTIONAL EXPENSES

<table>
<thead>
<tr>
<th>INSTRUCTIONAL EXPENSES TOTAL</th>
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<tbody>
<tr>
<td>Instructional supplies, books, lab supplies</td>
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<tr>
<td>INSTRUCTIONAL EXPENSES TOTAL</td>
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### ADVERTISING

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<th>ADVERTISING TOTAL</th>
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<tr>
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<td>Print materials and program marketing</td>
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### MISCELLANEOUS OPERATING EXPENSES

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### SUMMARY

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<th>Year</th>
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<tr>
<td>06/30/22</td>
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<tr>
<td>06/30/23</td>
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<tr>
<td>06/30/24</td>
<td>$232,204</td>
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<td>06/30/25</td>
<td>$435,309</td>
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<tr>
<td>06/30/26</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td>$2,532,112</td>
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<tr>
<td>Supplies (paper, ink, general office supplies)</td>
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<td>Website Support</td>
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<td><strong>MISC OPERATING EXPENSES TOTAL</strong></td>
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<tr>
<td><strong>OTHER COSTS</strong></td>
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<td><strong>OTHER COSTS TOTAL</strong></td>
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<td><strong>TOTAL COSTS</strong></td>
<td><strong>$1,545,998</strong></td>
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## Biological Engineering PhD Program Full Budget

<table>
<thead>
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<th>FACULTY SALARIES</th>
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<tbody>
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<td><strong>Chair: R. Pruett</strong></td>
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<tr>
<td>$19,694</td>
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<tr>
<td>$259,594</td>
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<td>$164,797</td>
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<tr>
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<tr>
<td>$300,156</td>
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<td>$185,460</td>
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<tr>
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</tr>
<tr>
<td><strong>Faculty: K. Plaxco</strong></td>
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<tr>
<td><strong>Faculty: A. McIver</strong></td>
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<tr>
<td>$179,877</td>
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<tr>
<td>$182,827</td>
<td>Annually</td>
<td>$92,181</td>
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<tr>
<td><strong>Faculty: S. Smith</strong></td>
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<tr>
<td>$169,920</td>
<td>Annually</td>
<td>$84,960</td>
</tr>
<tr>
<td>$175,614</td>
<td>Annually</td>
<td>$87,690</td>
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<tr>
<td>$180,246</td>
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<tr>
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<td>$92,842</td>
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<tr>
<td><strong>Faculty: S. Streichman</strong></td>
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</tr>
<tr>
<td>$116,162</td>
<td>Annually</td>
<td>$58,102</td>
</tr>
<tr>
<td>$119,690</td>
<td>Annually</td>
<td>$59,940</td>
</tr>
<tr>
<td>$125,208</td>
<td>Annually</td>
<td>$61,440</td>
</tr>
<tr>
<td>$126,979</td>
<td>Annually</td>
<td>$61,499</td>
</tr>
<tr>
<td>$130,788</td>
<td>Annually</td>
<td>$65,394</td>
</tr>
<tr>
<td><strong>Prof/Assoc Prof/Assist Prof/TID</strong></td>
<td>6</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$3,575,001</td>
<td>$1,188,698</td>
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</tbody>
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### Yearly Budget Breakdown

- **FACULTY SALARIES SUBTOTAL:**
  - Year 1: $120,000
  - Year 2: $120,000
  - Year 3: $120,000
  - Year 4: $120,000
  - Year 5: $120,000
  - Total: $600,000

- **INSTRUCTIONAL SUPPORT:**
  - Teaching Assistant FTE: 9
  - Graduate Program: 3
  - Total: $67,440

---

1.
### FRINGE BENEFITS

<table>
<thead>
<tr>
<th>Description</th>
<th>Base Rate</th>
<th>Annual Pay</th>
<th>Semi-Annual Pay</th>
<th>Quarterly Pay</th>
<th>Monthly Pay</th>
<th>Bi-Weekly Pay</th>
<th>Weekly Pay</th>
<th>Hourly Pay</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Faculty Benefits</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Rate</td>
<td>$1,079,991</td>
<td>$3,910,240</td>
<td>$2,172,100</td>
<td>$434,420</td>
<td>$138,140</td>
<td>$69,070</td>
<td>$15,490</td>
<td>$6.67</td>
</tr>
<tr>
<td><strong>Staff Exempt Benefits</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Rate</td>
<td>$174,189</td>
<td>$532,568</td>
<td>$266,284</td>
<td>$66,571</td>
<td>$21,857</td>
<td>$10,928</td>
<td>$2,265</td>
<td>$10.50</td>
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<tr>
<td><strong>Staff Non-Exempt Benefits</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Rate</td>
<td>$200,480</td>
<td>$721,680</td>
<td>$360,840</td>
<td>$90,210</td>
<td>$30,070</td>
<td>$15,035</td>
<td>$3,758</td>
<td>$17.10</td>
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</table>

### STAFF SALARIES SUBTOTAL

<table>
<thead>
<tr>
<th>Description</th>
<th>Base Rate</th>
<th>Annual Pay</th>
<th>Semi-Annual Pay</th>
<th>Quarterly Pay</th>
<th>Monthly Pay</th>
<th>Bi-Weekly Pay</th>
<th>Weekly Pay</th>
<th>Hourly Pay</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Business Officer E. Jensen (Upward Reclassification)</strong></td>
<td>$104,469</td>
<td>$377,776</td>
<td>$193,890</td>
<td>$48,473</td>
<td>$16,158</td>
<td>$8,079</td>
<td>$1,879</td>
<td>$10.80</td>
</tr>
<tr>
<td><strong>Student Affairs Manager, Student Services Advisor 3 (New Position)</strong></td>
<td>$70,000</td>
<td>$260,000</td>
<td>$130,000</td>
<td>$32,500</td>
<td>$10,833</td>
<td>$5,417</td>
<td>$1,204</td>
<td>$6.50</td>
</tr>
<tr>
<td><strong>Student Services Advisor 2 - A. Toporov</strong></td>
<td>$57,800</td>
<td>$223,200</td>
<td>$111,600</td>
<td>$27,900</td>
<td>$9,300</td>
<td>$4,650</td>
<td>$1,038</td>
<td>$5.75</td>
</tr>
<tr>
<td><strong>Financial Analyst 2 (New Position)</strong></td>
<td>$60,000</td>
<td>$240,000</td>
<td>$120,000</td>
<td>$30,000</td>
<td>$10,000</td>
<td>$5,000</td>
<td>$1,250</td>
<td>$6.25</td>
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<tr>
<td><strong>Academic Personnel Payroll Analyst, Admin Officer 2 (New Position)</strong></td>
<td>$65,000</td>
<td>$260,000</td>
<td>$130,000</td>
<td>$32,500</td>
<td>$10,833</td>
<td>$5,417</td>
<td>$1,204</td>
<td>$6.50</td>
</tr>
<tr>
<td><strong>Events Assistant, Blanks Assistant 3 (New Position)</strong></td>
<td>$22,500</td>
<td>$85,500</td>
<td>$42,750</td>
<td>$10,687</td>
<td>$3,562</td>
<td>$1,818</td>
<td>$393</td>
<td>$2.15</td>
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</table>

### SALES TOTAL

**$3,548,257**
<table>
<thead>
<tr>
<th>STUDENT Benefits</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Sum: $94,381</td>
<td>1.9% $1,793</td>
</tr>
<tr>
<td>Base Sum: $96,861</td>
<td>1.9% $1,840</td>
</tr>
<tr>
<td>Base Sum: $27,648</td>
<td>1.9% $525</td>
</tr>
<tr>
<td>Base Sum: $102,048</td>
<td>1.9% $1,939</td>
</tr>
<tr>
<td>Base Sum: $28,620</td>
<td>1.9% $544</td>
</tr>
<tr>
<td>Base Sum: $107,550</td>
<td>1.9% $2,043</td>
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</table>

<table>
<thead>
<tr>
<th>Graduate Student Health Insurance Benefits</th>
<th>*</th>
</tr>
</thead>
<tbody>
<tr>
<td>$17,782</td>
<td>$19,383</td>
</tr>
<tr>
<td>$21,902</td>
<td>$23,654</td>
</tr>
<tr>
<td>$25,547</td>
<td>$27,591</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Graduate Student Tuition and Fee Remission (in-state)</th>
<th>*</th>
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</thead>
<tbody>
<tr>
<td>$46,090</td>
<td>$47,242</td>
</tr>
<tr>
<td>$48,423</td>
<td>$49,634</td>
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<tr>
<td>$50,875</td>
<td>$52,147</td>
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<table>
<thead>
<tr>
<th>BMES Travel to BMES Annual Meeting (1 Faculty, 2 staff)</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>$9,000</td>
<td>$9,270</td>
</tr>
<tr>
<td>$9,548</td>
<td>$9,835</td>
</tr>
<tr>
<td>$10,130</td>
<td>$10,433</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Student Travel Awards (Conferences/ Presentations)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$10,000</td>
<td>$10,000</td>
</tr>
<tr>
<td>$10,000</td>
<td>$10,000</td>
</tr>
<tr>
<td>$10,000</td>
<td>$10,000</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Travel awards for BIC Symposium (3 students, 1 Faculty, 1 staff)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$5,250</td>
<td>$5,408</td>
</tr>
<tr>
<td>$5,570</td>
<td>$5,737</td>
</tr>
<tr>
<td>$5,909</td>
<td>$6,086</td>
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<table>
<thead>
<tr>
<th>Travel TOTAL</th>
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<tbody>
<tr>
<td>$35,250</td>
<td>$36,008</td>
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<tr>
<td>$36,788</td>
<td>$37,591</td>
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<tr>
<td>$38,419</td>
<td>$39,272</td>
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<table>
<thead>
<tr>
<th>BMES</th>
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</thead>
<tbody>
<tr>
<td>$17,782</td>
<td>$19,383</td>
</tr>
<tr>
<td>$21,902</td>
<td>$23,654</td>
</tr>
<tr>
<td>$25,547</td>
<td>$27,591</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>EVENTS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Recruitment Events, orientation, student admittance day</td>
<td></td>
</tr>
<tr>
<td>$8,000</td>
<td>$8,270</td>
</tr>
<tr>
<td>$8,548</td>
<td>$8,835</td>
</tr>
<tr>
<td>$9,130</td>
<td>$9,433</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Biotechnology Industry Showcase</th>
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</tr>
</thead>
<tbody>
<tr>
<td>$4,000</td>
<td>$4,000</td>
</tr>
<tr>
<td>$4,500</td>
<td>$4,500</td>
</tr>
<tr>
<td>$5,000</td>
<td>$5,000</td>
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</table>

<table>
<thead>
<tr>
<th>EVENTS TOTAL</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$9,000</td>
<td>$9,150</td>
</tr>
<tr>
<td>$9,805</td>
<td>$9,864</td>
</tr>
<tr>
<td>$10,628</td>
<td>$10,796</td>
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</table>

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Shared Microscope</td>
<td>$350,000</td>
</tr>
<tr>
<td>Furniture 2 offices @$5000</td>
<td>$10,000</td>
</tr>
</tbody>
</table>

| EQUIPMENT TOTAL |  |
|----------------||--|
| $360,000 | $0 |
| $0 | $0 |
| $0 | $0 |
| $0 | $0 |

<table>
<thead>
<tr>
<th>INSTRUCTIONAL EXPENSES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructional supplies, books, lab supplies</td>
<td>$30,000</td>
</tr>
<tr>
<td>$30,000</td>
<td>$31,827</td>
</tr>
<tr>
<td>$32,782</td>
<td>$34,778</td>
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</table>

<table>
<thead>
<tr>
<th>ADVERTISING</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Newsletters and online</td>
<td>$10,000</td>
</tr>
<tr>
<td>$10,300</td>
<td>$10,609</td>
</tr>
<tr>
<td>$10,927</td>
<td>$11,255</td>
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<table>
<thead>
<tr>
<th>ADVERTISING TOTAL</th>
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<tbody>
<tr>
<td>$22,000</td>
<td>$22,660</td>
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<tr>
<td>$23,340</td>
<td>$24,040</td>
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<tr>
<td>$24,761</td>
<td>$25,504</td>
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<table>
<thead>
<tr>
<th>MISC OPERATING EXPENSES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Telephone charges</td>
<td>$500</td>
</tr>
<tr>
<td>$500</td>
<td>$500</td>
</tr>
<tr>
<td>$500</td>
<td>$500</td>
</tr>
<tr>
<td>$500</td>
<td>$500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OTHER COSTS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6. START UP PACKAGE (1) $680K AVERAGE</td>
<td></td>
</tr>
<tr>
<td>$680,000</td>
<td>$680,000</td>
</tr>
<tr>
<td>$680,000</td>
<td>$680,000</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>OTHER COSTS TOTAL</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$4,080,000</td>
<td>$4,080,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TOTAL COSTS</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>$3,394,264</td>
<td>$3,100,236</td>
</tr>
<tr>
<td>$3,189,667</td>
<td>$3,298,306</td>
</tr>
<tr>
<td>$3,405,948</td>
<td>$3,498,398</td>
</tr>
<tr>
<td>$4,388,421</td>
<td>$4,080,000</td>
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