

A Novel Engineering Systems Approach for Bioengineering Education: the MIT-Portugal Collaboration

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Abstract – This paper discusses the importance of an engineering systems approach to international bioengineering education and how a new educational-research program, the MIT-Portugal Program Bioengineering Systems focus area, aims to develop future global bioengineering leaders. The program, comprising both post-graduate advanced studies and doctoral programs, commences in September 2007. Several other international-collaborative educational and research programs—such as the Cambridge-MIT Institute, the Singapore MIT Alliance, and the Socrates/Erasmus “Erasmus Programme”—offer lessons learned in international collaboration. The MPP Bioengineering Systems program differs from these programs in several respects. The unique collaboration in MPP offers an engineering systems approach, a joint degree offered by three Portuguese universities, and collaborative teaching and research efforts between MIT and Portuguese faculty and students.

Index Terms – MIT-Portugal, Bioengineering Education, International Education Programs, Engineering Systems Education

INTRODUCTION

This paper describes the educational goals, philosophy, and structure of the MIT-Portugal Program’s (MPP) bioengineering systems focus area, which we hope will be one model for successful international multi-university programs. As points of reference, this paper also compares and contrasts the MPP bioengineering systems program with several other university collaborative and exchange programs, such as the Singapore-MIT Alliance, the Cambridge-MIT Initiative, and the European ERASMUS program.

BRIEF OVERVIEW OF THE MIT-PORTUGAL PROGRAM

The MIT-Portugal Program (MPP) is a five-year collaboration between Portuguese universities, research laboratories, and industry with the Massachusetts Institute of Technology (MIT). It is funded by the Portugal Ministry of

Science, Technology and Higher Education. The program’s overall theme is large-scale complex engineering systems. Based on initial education and research assessments, MIT and Portugal representatives selected five program focus areas: (1) sustainable energy systems, (2) transportation systems, (3) engineering design/advanced manufacturing, (4) bioengineering systems, and (5) the cross-cutting area of engineering systems. This paper details only the bioengineering systems focus area.

The Portuguese government’s objectives for the program are to enhance Portuguese universities, develop human resources, generate knowledge, promote internationalization, foster university-industry relationships, and promote economic development. MPP is currently MIT’s largest program in Europe [1]. The program description is as follows:

The Portuguese Government, through the Ministry of Science, Technology and Higher Education, entered into a long-term collaboration with the Massachusetts Institute of Technology (MIT) focusing on basic research and education. The objectives, framework and structure of the collaboration were developed during a five month assessment study conducted by MIT between February and July 2006, which concluded that the excellence of the research identified in Portuguese research centers throughout the assessment exercise recommends that MIT foster collaborations with Portuguese institutions. Also, the study acknowledges that the commitment of the Portuguese Government in strengthening science and technology and in promoting international collaborations in higher education and in science and technology is making Portugal an interesting place for doing research and a relevant partner for future collaborations in the emerging knowledge-based, globalized economy.

The Portuguese Government intends to strengthen the country’s knowledge base at an international level through a strategic investment in people, knowledge and ideas and the MIT-Portugal Program has been designed together with other international partnerships with renowned research and education institutions worldwide

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to contribute adequate funding to support the development of basic research and education and to foster a set of new and diversified institutional partnerships. It should also be noted that the goals of the overall operation include launching and promoting new research-based consortia at a national level and the MIT-Portugal Program contributes for this effort by involving 10 schools of higher education and 7 different universities, together with a large number of research centres and Associated Laboratories, as well as State Laboratories [2].

We now discuss the MPP bioengineering systems focus area. The objectives of the bioengineering systems program are to promote new inter-institutional post-graduate training

and opportunities; create a new generation of bioengineering leaders in Portugal; create new knowledge; and to promote industrial, health-care, and environmental biotechnology education and research that make possible new start-ups and that implement new models of interaction between universities, enterprises, government, and society [3][4]. The three lead Portuguese universities for the bioengineering systems area are Instituto Superior Técnico (IST), Universidade Nova de Lisboa (Nova), and Universidade do Minho (Minho). Other participating institutions include the Center for Neuroscience and Cell Biology (CNC), Universidade de Coimbra, Instituto Gulbenkian de Ciencia, Universidade do Algarve, and the Universidade do Porto. Figure 1 provides an overview of the MPP Bioengineering Systems program.

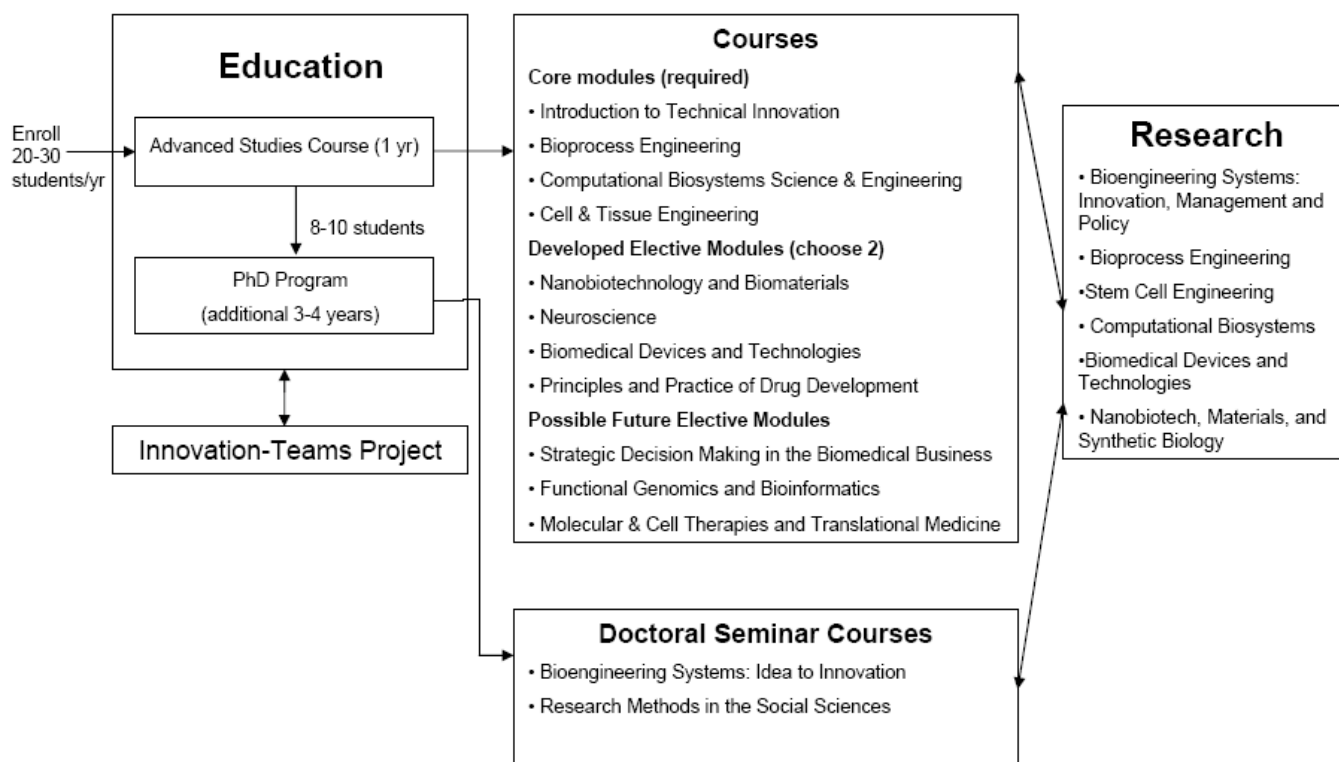


FIGURE 1: EDUCATION AND RESEARCH OVERVIEW OF THE MIT PORTUGAL PROGRAM BIOENGINEERING SYSTEMS COLLABORATION [3][4]

AN ENGINEERING SYSTEMS APPROACH TO BIOENGINEERING IN PORTUGAL

MIT's Engineering Systems Division (ESD) serves as the lead MIT entity for the MPP. A brief discussion of MIT's ESD is instructive because it outlines some of the key ideas and goals behind MPP. MIT established ESD in 1999 as an interdisciplinary unit within the school of engineering. The division is similar to a department in its power to appoint, promote, and tenure faculty, as well as to admit and award degrees to students. But it differs from a traditional engineering department in its faculty sharing (all faculty with ESD appointments also have appointments in another department) as well as in its strong collaborations with other schools at MIT, such as the School of Humanities, Arts, and Social Sciences (HASS), the Sloan School of Management, the School of Science, and the School of Architecture and

Planning. In other words, ESD cuts across departmental and school boundaries [5].

ESD grew out of the realization that traditional engineering approaches were inadequate for dealing with today's large, complex engineering systems (ES), specifically the socio-technical global challenges that the world faces. Engineering leaders of the future must be educated in technical, political, economic and social methods to solve these global challenges. Examples of ES include automotive plants, aircraft manufacturing, computer operating systems, power generation systems, clean water and air infrastructure and systems. ESD distinguishes ES from traditional engineering approaches and other multidisciplinary engineering approaches (e.g., operations research) by its holistic way of thinking about ES, which involves emphasizing "the behavior or structure of the whole in contrast to its parts" [5]. This holistic view encompasses such issues as life-cycle perspective, systems architecture,

safety, sustainability, organization and management, feedback processes, and socio-political realities. ES involve porous boundaries between technical systems and their environments, prompting ES practitioners to recognize economic, social, and political contexts of engineering systems

Portugal's Secretary of State remarked that an engineering systems approach has been adopted for MPP so that Portuguese universities emphasize "large-scale systems that not only have critical technological components, but also...significant enterprise and socio-technical" interactions. The goal is for these new ways of thinking to "promote new engineering research in Europe" [6]. For bioengineering specifically, engineering systems thinking can help integrate this area with the other focus areas, such as advanced manufacturing and energy, since life science developments can drive developments in these areas and vice versa. Also, engineering systems thinking will help us better understand how universities, industry, and government can beneficially work together, which is especially critical for biotechnology industry development.

The bioengineering profession requires a systems-level view because jobs will involve a mixture of social science, economics, and public policy. In industry, bioengineers must understand how their devices will be used and by who, which in turn requires understanding markets and social factors. In government, bioengineers will contribute to public policy and regulation, which requires them to understand law, social science, and economics. In startups, bioengineers must understand business and leadership. The myriad of legal, ethical, societal, and political issues surrounding medical technologies means that bioengineering will be a complex field requiring systems thinkers.

STRUCTURE OF MPP'S BIOENGINEERING SYSTEMS AREA

The bioengineering systems area comprises two academic programs: (1) a one year Advanced Studies Course (ASC) and (2) a doctoral PhD program. Table 1 presents the two educational tracks. Both programs include one year of intensive coursework (4 course core modules) and an additional two elective course modules. The first year also involves an Innovation Teams (i-Teams) bioengineering project. The final components of the first year are research visits and placements. The goal is to admit ~20 students the first year followed by 30 students each year thereafter (years 2-5). The ASC terminates after one year of immersion, while the PhD program continues for three to four years of additional study beyond the first year. Eight to ten top students each year will be admitted to the doctoral program after successfully completing the first year educational program. Students in the MPP bioengineering systems doctoral track will have the opportunity to be "visiting students" at MIT in collaborating labs and will typically spend 12-18 months at MIT on their doctoral research and an equivalent amount of time at their home research laboratory in Portugal. Research collaborations are planned between MIT and Portuguese faculty. These collaborations will allow students in the MPP program to perform part of their

research at their home laboratory in Portugal and at collaborating MIT research laboratories.

TABLE 1: TWO EDUCATIONAL TRACKS IN MPP BIOENGINEERING [3][4]

	Advanced Studies Course	PhD Program
Year 1, fall	4 courses 2 elective courses	4 courses 2 elective courses
Year 1, spring	Research experience i-Teams Project	Research initiation & placement i-Teams Project
Years 2 to 5	ASC repeats yearly	Additional Coursework 12-18 months research at MIT 1-2 years research in Portugal

Each course module is typically an intensive two-week module that may include a combination of lectures, labs, and seminars. Generally, courses will be co-taught by MIT and Portuguese faculty, although in some instances distance learning (i.e., video lectures) may be used.

Table 2 details the MPP bioengineering course modules.

Since two focus areas of the bioengineering systems program are leadership development and transfer of academic research into successful start-up companies, the program will develop an innovation module for Portugal, based on MIT's Innovation Teams (i-Teams) framework, but with appropriate cultural awareness and projects that are best suited for Portugal. i-Teams is a course offered by MIT's School of Engineering and the Sloan School of Management in which teams of 4-5 graduate students "assess the commercial feasibility" of current MIT research projects. The projects are typically faculty research projects funded by MIT's Deshpande Center, which, among other entrepreneurial support activities, provides grants for faculty to pursue research projects with commercial applications [7][8]. During the semester, students—who may include MBA and science/engineering graduate students—determine what the best strategy the faculty member and his or her students should take regarding the technology, such as developing it further, licensing it, or creating a start-up. Students also participate in lectures with technology entrepreneurs and venture capitalists, engage in networking activities, and interact with entrepreneur/venture capitalist mentors [9]. The exact structure and curriculum for the Portuguese i-Teams course is currently under development to be offered for the first time in Sept. 2007.

Other parts of the bioengineering systems program include industry participation, symposia and workshops, community outreach, and linkages to other focus areas. Several Portuguese biotechnology companies have participated in workshops and curriculum development, and bioengineering systems faculty have been seeking more companies for potential research collaborations. Workshops on *Innovation in Bioengineering* (November, 2006 and January, 2007) have provided opportunities for MPP faculty and biotechnology industry professionals in Portugal to interact, share ideas and provide feedback on program development. A Workshop on *Biomaterials and Biomedical Devices* (Jan. 2007) was held at the Univ. of Minho in northern Portugal to bring together speakers from academia and industry. Future workshops are scheduled for June 2007

on *Government, Industry and Academia relations*. Bioengineering systems faculty are also dedicated to providing outreach to young learners and have lectured to hundreds of high school students in collaboration with Portugal's *Ciência Viva* of the *Agência Nacional para a*

Cultura Científica e Tecnológica [3]. Finally, collaboration with other MPP program areas, especially in Innovation and Medical Devices and Technologies, and MIT social science faculty have also been established [4].

TABLE 2: EDUCATIONAL CURRICULUM FOR THE BIOENGINEERING COURSE MODULES [3][4]

	Course Module	Description	Format
Core modules	1. Introduction to Technological Innovation	Prerequisite course for spring semester i-Teams project. Exposes students to systems thinking and offers innovation training. Collaboration with Engineering Design/Advanced Manufacturing focus area.	Seminars Leadership building activities
	2. Bioprocess Engineering	Covers fundamentals on Growth and Metabolism, Enzyme kinetics and enzyme bioreactors, fermentation technology, media and air sterilization, transport phenomena, etc.	Lectures co-taught by MIT/Portuguese faculty
	3. Cell & Tissue Engineering	Covers cell and development biology, animal cell culture, stem cell and tissue engineering fundamentals. Includes seminars and journal club.	Lectures co-taught by MIT/Portuguese faculty; Seminar Series with invited speakers; Journal club
	4. Computational Biosystems Science and Engineering	Covers computational biology, algorithms and optimization, bioinformatics, and other related topics.	Lectures co-taught by MIT/Portuguese faculty; computer modeling labs
Elective Courses	1E. Biomedical Devices and Technologies	Covers issues related to development of hybrid human machine technologies for biomedical applications	Lectures co-taught by MIT/Portuguese faculty; two lab days; industry visiting day
	2E. Nanobiotechnology and Biomaterials	Covers scientific basis of nanotechnology and biomaterials applied to biomedical engineering and bioengineering	Lectures co-taught by MIT/Portuguese faculty
	3E. Neuroscience: Molecular to Systems Neurobiology and Brain Diseases	Covers neuroscience and related topics.	Lectures co-taught by MIT/Portuguese faculty; possibly invited speakers
	4E. Principles and Practice of Drug Development	Covers the description and critical assessments of major issues and stages of developing a pharmaceutical.	Distance learning course

COMPARISON WITH OTHER UNIVERSITY COLLABORATIVE PROGRAMS

Although comparisons with other inter-university collaborative programs is imperfect due to differences in scope and goals, we nevertheless find it instructive to highlight some similarities and differences between MPP and three other programs, focusing on bioengineering in particular: the Singapore-MIT Alliance (SMA), the Cambridge-MIT Institute (CMI), and the ERASMUS program ("European Community Action Scheme for the Mobility of University Students").

SMA is an engineering education and research collaboration among the National University of Singapore (NUS), Nanyang Technological University (NTU), and MIT. It began in 1998 as phase 1 (SMA-1) and entered Phase 2 (SMA-2) in 2005, which expanded the program [10]. Like MPP, SMA specifically focuses on graduate education and research, as well as on entrepreneurship and commercialization of university research. SMA's goals include attracting and developing human capital in

Singapore, creating world-class educational programs and research initiatives in areas crucial to Singapore's economic growth, and foster strong academia-industry-research institute linkages [11]. Research collaborations between MIT, NUS, and NUT provide students the opportunity to work on interdisciplinary, international research. As with MPP, SMA awards certificates, masters, and doctorate degrees in certain focus programs. These five SMA-2 programs are (1) Advanced materials for micro- and nano-systems, (2) Chemical and pharmaceutical engineering, (3) Computational and systems biology, (4) Computational engineering, and (5) Manufacturing systems and technology. SMA students also participate in internships hosted by affiliated companies [12].

Of these five programs, the Computational and Systems Biology (CSB) program and the Chemical and Pharmaceutical Engineering (CPE) program are most closely related to MPP's bioengineering systems program. CSB admitted 10 students out of 82 applicants for the 2005/2006 year. CPE program statistics have not been released, but a previous related program from SMA-1, the Molecular Engineering of Biological and Chemical Systems (MEBCS)

program, enrolled 35 applicants out of 114 applicants in 2005/2006. MPP bioengineering aims to admit ~30 students each year [10]. The class structure of the SMA programs is different from MPP in that they are full semester (14 week) distance learning video classes taken directly from MIT courses. In MPP bioengineering systems, students take condensed two-week course modules typically co-taught by MIT and Portuguese faculty. As with MPP, SMA students have the opportunity to study at MIT for a certain amount of time, which varies depending on academic track. Another difference between SMA and MPP bioengineering systems is the geographic scale of the program. SMA involves two Singapore universities in the same city, while MPP bioengineering involves multiple universities and labs spread throughout Portugal. For this reason, logistical planning and close collaboration between Portuguese universities is crucial for MPP's success.

CMI was launched in July, 2000, as a new international collaborative program between MIT and Cambridge University to explore how "academics, industrialists and educators might work together to stimulate competitiveness, productivity and entrepreneurship" [13]. CMI has developed new Master's of Philosophy (MPhil) degrees at Cambridge University, including some aimed at technology policy, bioengineering entrepreneurship, and sustainability. Other programs developed under CMI include a highly successful undergraduate student exchange between Cambridge and MIT; WebLabs, a system that allows Cambridge students to perform live experiments with MIT hardware via the internet, and the Programme on Regional Innovation, which brings together faculty to work on projects that promote regional innovation and development in the UK. One similarity between CMI and MPP is both programs' emphasis on commercialization of university research. Also, both programs integrate an Innovation framework as a means to achieve this goal [13]. However, the programs differ since MPP also focuses strongly on academic research. Also, the programs may be seen as catering to different student segments: MPP generally caters to students entering graduate school, while CMI also focuses on undergraduates and mid-career professionals, such as through its Mid-Career Enterprise Education in Technology and Science course for female entrepreneurs.

The ERASMUS programme was launched in 1987 and currently involves over 150,000 European Union (EU) students each year [14]. ERASMUS's objectives are to (1) support the European activities of higher education institutions, and (2) promote the mobility and exchange of their teaching staff and students [15]. Universities participate in the ERASMUS programme by applying to the European Commission to be awarded an Erasmus charter. Currently, 90% of EU universities participate in Erasmus [16].

ERASMUS lets EU students study at other Erasmus chartered EU universities for three to twelve months by providing a study grant and ensuring that course credits will count at the students' home universities. Students must have completed at least one year of undergraduate study and can be enrolled in any degree program up to and including the doctorate. Erasmus language courses are offered at host universities to help students learn the necessary foreign

language [17]. Erasmus also provides university teaching staff the opportunity to teach at another Erasmus university for periods of one week to six months [18]. ERASMUS is therefore a very different program from MPP both in scale and in that it is a foreign exchange program rather than a degree-granting program. Also, ERASMUS is open to any field of study, while MPP focuses on specific disciplines.

In 2004/2005, 3,845 Portuguese students participated in ERASMUS. Of the 119,802 European 18 country students who participated in ERASMUS during that year, 12,612 were from engineering, 6,163 were from medical sciences, and 4,397 were from natural sciences [19]. A comparison of these four international programs is presented in Table 3.

TABLE 3: COMPARISON OF FOUR INTERNATIONAL EDUCATIONAL PROGRAMS [3][4] [13] [11][12] [16]

Program	MPP Bioengineering Systems	Cambridge-MIT Initiative	Singapore-MIT Alliance	ERASMUS
Degrees awarded	1yr ASC PhD	MPhil	MS PhD	None
General curriculum structure	2-week course modules 12-week semesters	8-week semesters	1 semester MIT distance learning classes	Normal university classes
Duration	1 yr ASC 4-5 yr PhD	9-12 months	18 month MS/SM Doctorate	3-12 months
Focuses on university innovation	Yes	Yes	Yes	No

Grindel et al. (2006) convened scholars from eight international universities to conduct a year-long study on global engineering and global engineering education. The team identified four common problems in international engineering programs. First, international elements are often add-ons to an existing engineering curriculum instead of a fully integrated international study program within the degree program. Second, there are often problems with international mobility, such as student visas and cost issues. Third, many partnerships are not well conceived, leading to isolated efforts. Fourth, most programs are not scientifically analyzed to determine effectiveness [20].

We believe MPP addresses the first three concerns because it is an integrated international engineering academic program designed in close collaboration between multiple universities. Issues such as student mobility, collaborative research projects, and long-term program sustainability are being considered and addressed.

CONCLUSION

MPP is MIT's largest program in Europe, and our international collaboration aims to become a model program for global education and research efforts. For bioengineering systems, we will measure the program's success by three metrics: the level of new inter-institutional cooperation between Portuguese institutions, the MIT faculty participation in the implementation of education and research post-graduate training and opportunities, and the number and

quality of students in the MPP post-graduate opportunities. The MPP bioengineering systems program brings together over 60 faculty from Portugal, 20 faculty from MIT, and 30 students each year in a new international collaboration.

Students will benefit from such a global partnership by gaining greater exposure to other cultures (e.g., European vs. American), being exposed to new ways of thinking, and having access to a larger pool of researchers and educators. These experiences will be crucial in helping create what the U.S. National Academy of Engineering envisions as the Engineers of 2020: professionals who are “well grounded in the basics of mathematics and science” but will also “expand their vision of design through a solid grounding in the humanities, social sciences, and economics” in order to demonstrate “effective leadership in the development and application of next-generation technologies to problems of the future” [21].

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