Committee for the Evaluation of Medical and Biomedical Engineering Study Programs

General Report

January 2017

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Chapter 1- Background

The Council for Higher Education (CHE) decided to evaluate study programs in the field of Medical and Biomedical Engineering during the academic year of 2016.

Following the decision of the CHE, Vice Chair of the Council of Higher Education on behalf of the Minister of Education, appointed a Committee consisting of:

- Prof. C. Ross Ethier- Department of Biomedical Engineering at Georgia Institute of Technology & Emory University School of Medicine, USA committee Chair
- Prof. James Moore- Faculty of Engineering, Department of Bioengineering, London Imperial College, UK
- Prof. Milica Radisic- Faculty of Applied Sciences and Engineering, University of Toronto, Canada
- Prof. Amit Gefen- Department of Biomedical Engineering, Tel Aviv University, Israel

Ms. Alex Buslovich Bilik was the coordinator of the Committee on behalf of the CHE.

Within the framework of its activity, the Committee was requested to:[1]

1. Examine the self-evaluation reports, submitted by the institutions that provide study programs in Medical and Biomedical Engineering and to conduct on-site visits at those institutions.
2. Submit to the CHE an individual report on each of the evaluated academic units and study programs, including the Committee's findings and recommendations.
3. Submit to the CHE a general report regarding the examined field of study within the Israeli system of higher education including recommendations for standards in the evaluated field of study.

The entire process was conducted in accordance with the CHE's Guidelines for Self-Evaluation (of October 2015).

[1] The Committee's letter of appointment is attached as **Appendix 1**.

Chapter 2-Committee Procedures

The Committee held its first meetings on November 27th 2016, during which it discussed fundamental issues concerning higher education in Israel, the quality assessment activity, as well as Medical and Biomedical programs in Israel.

During Novemebr and December 2016, the Committee held its visits of evaluation, and visited, Tel Aviv University, Ben Gurion University, the Technion and Afeka academic college. During the visits, the Committee met with various stakeholders at the institutions, including management, faculty, staff, and students.

The schedule of the visit is attached as **Appendix 2**.

Chapter 3: Evaluation of Medical and Biomedical Engineering

1. *The Context of Medical and Biomedical Engineering*

Terminology: Biomedical Engineering vs. Medical Engineering vs. Bioengineering: For purposes of clarity it is important to define terminology, since this is not necessarily understood by those outside the field. Biomedical Engineering (BME) is the most commonly used term and usually refers to the application of principles from engineering and life sciences to the understanding of physiology and pathophysiology in humans, and to the treatment of disease in humans. This discipline covers a very broad range of topics, such as: design and testing of implants, medical imaging, tissue engineering, biomaterials and cell-based therapies, etc. Medical engineering is slightly more focused, usually restricting itself to the treatment of disease in humans, e.g. incorporating medical devices and clinical imaging. Finally, bioengineering includes biomedical engineering but also encompasses the use of engineering and life science principles to study problems in organisms other than humans. Here we will use the term BME to refer to the general field of Medical and Biomedical Engineering.

BME is an emerging field and there is no "standard" curriculum or set of sub-disciplines: It is important to understand that BME is the newest engineering discipline, with many Departments coming into existence only within the past 20 years. Generally speaking, there is not a "canonical" curriculum for BME programs, and this is often a subject of vigorous discussion within the academy. Further, BME is an extremely broad field and there is a correspondingly broad range of research topics represented in many BME Departments around the world. We are unaware of any Department that covers all subtopics within BME as part of their research portfolio.

"Classical" BME vs. "Modern" BME: The final aspect of context-setting is the nature of teaching and research. BME grew out of sister engineering disciplines and in the past was very much grounded in engineering and physics, with less biology. This has led to many successful clinical technologies, e.g. medical implants, and is the basis for the majority of BME industry at present. However, due to the diffusion of life sciences into BME, this landscape is changing. Some Departments around the world remain very "classical", while others (e.g. the Biological Engineering Department at MIT) have moved aggressively to become much more biologically-based. Correspondingly, there is now an emerging industry base that is more biologically based, e.g. cell-based therapies, tissue-engineered therapies, etc. Most departments span a range of expertise along this "classical" to "modern" spectrum.

Further, it should be noted that, in addition to those trained as Biomedical Engineers, the BME field draws experts from a range of conventional science and engineering fields including physicists, biologists, chemists, mathematicians, mechanical engineers, electrical engineers, etc. Outside Israel, a large number of bioengineering specialists work in manufacturing industries, such as pharmaceutical manufacturing, medical instrument development, and health care supply. In Israel, where there are fewer major companies and a higher ratio of start-ups, many biomedical engineers are involved in research & development; however, some are engaged in clinical trial supervisions and regulation, and others are working in satellite occupations such as in patents, technology analysis, or marketing and sales of medical devices. Thus, the employment landscape for BME graduates is very complex.

1. The Scope and Future of BME, and Israel's Role on the World Stage

BME is one of the fastest-growing areas of engineering. This is driven by several factors. First and foremost, medical care benefits greatly from technological advances, and BME graduates are best-placed to develop and deliver these advances. Second, demographic pressures are increasing the burden on health care systems, and BME can play a major role in cost efficiency and effectiveness in health care. Third, rapid advances in basic biological sciences are opening new opportunities for technological approaches to understanding and intervening in human health. Israeli BME students show great potential to contribute in these regards; however, this can only be realized by government investments in infrastructure and personnel in the institutions that are currently awarding BME degrees and which are training researchers, conducting research and working with industry

In view of the above, and although BME will remain smaller and more specialized than some of the more traditional engineering fields, the continued growth of BME is highly likely given rising life expectancies in the developed and developing countries. In fact, if BME were to shrink, this would be an indication that life expectancy and life quality were dropping – which would point to much more fundamental problems within human society. Clearly, this means that academia, including Israeli academia, must ensure strong, sustainable teaching and research programs in BME, from the undergraduate to the doctoral levels and from basic science to applied and industry-oriented research. The committee had this 'big picture' in mind when considering the topics that are discussed in detail in this report.

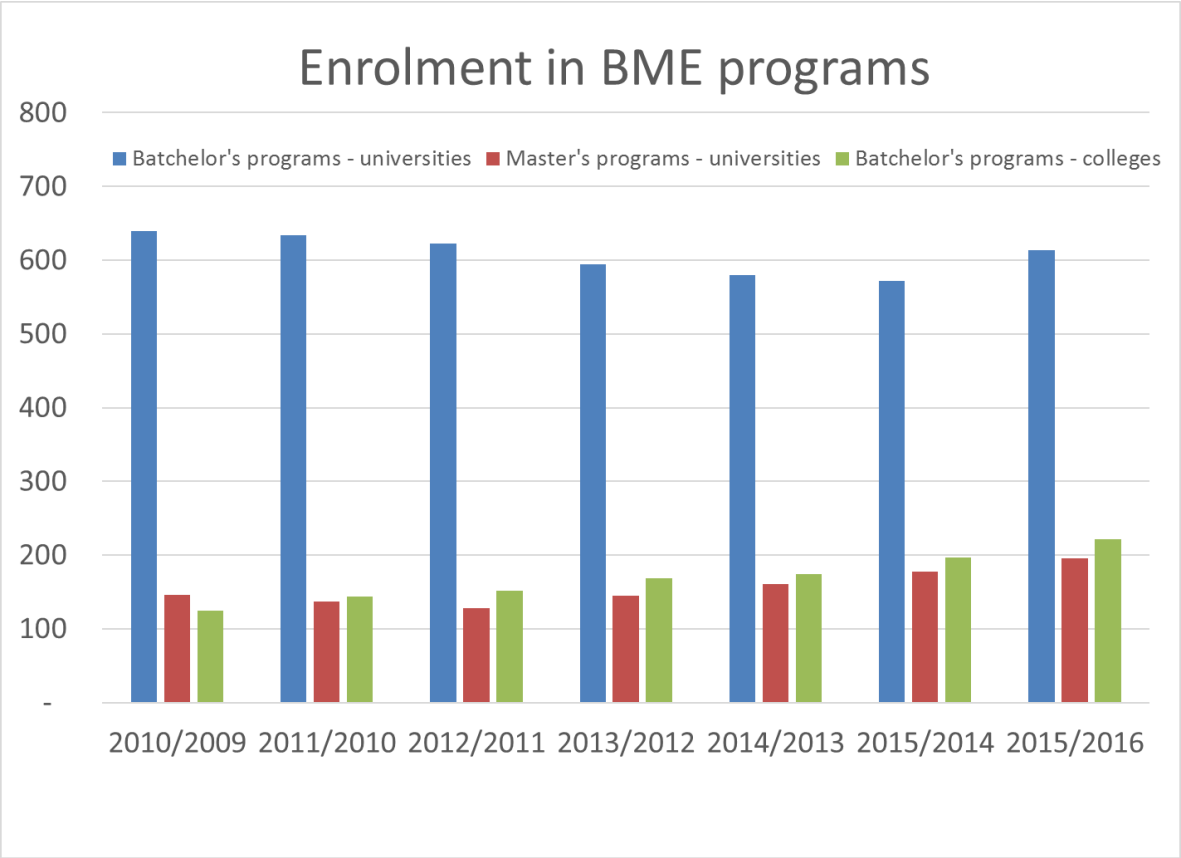
In order to benchmark the discipline within Israel, it is useful to compare Israeli student enrolment data with those from other countries. According to The Central Bureau of Statistics in Israel, the average number of undergraduate students enrolled in University-based programs in "Biomedical Engineering" within Israel over the term 2009/190-2015/16 was 608[2]. This can be compared to 2013 data from the US-based Accreditation Board for Engineering and Technology (ABET), which shows that there are 27,000 undergraduate students in ABET-accredited programs in in the USA. Considering that the Israeli population is 1/40 the size of the US population, this would imply that one would expect about 675 BME students in University-based BME programs in Israel if enrolment trends in Israel and the US were similar[3]. This is close to the actual number of students in University-based BME programs in Israel, which suggests that the Israeli higher-education system is not unbalanced at this point in time in the sense of having drastically fewer or more BME undergraduates than the USA, on a proportional basis.

Turning now to the number of programs, there are 110 ABET-accredited university-based BME programs in the USA. Using the same 40:1 ratio as in the previous paragraph, this would suggest that one should expect approximately 3 university-based BME departments in Israel, which is precisely the number of university-based Departments/Faculties that the Committee visited. Looking at the UK, there are 26 Universities offering Medical or Biomedical Engineering programs, and a similar calculation once again indicates that one would expect about 3 university-based BME departments in Israel. This suggests that the number of university-based BME departments is currently not unbalanced compared to other countries that are strong in BME education and research.

[2] This is an annual average as the enrolment fluctuates from year to year.

[3] We are aware that this is an imperfect comparison, inasmuch as the proportion of foreign students studying in the USA differs from that in Israel. Nonetheless, it is useful as a first-order estimate.

The growth of the BME discipline in the US and other countries is evident from surging student demand, growth of BME departments, and establishment of new BME Departments. This is in part due to employment prospects: the US Bureau of Labor Statistics expects biomedical engineers to have employment growth of about 70% over the next few years, much faster than the average for all occupations. Other Western countries, particularly European countries, exhibit similar trends and expected growth rates. This enrolment trend highlights a notable difference compared to Israel: the number of undergraduate students enrolled in university-based BME programs is Israel was flat or slightly declining over the past years (see graph, based on data from The Central Bureau of Statistics in Israel). The Committee is unsure of the reason(s) for these differences, and simply recommends that this situation be monitored. We also note that this slight decline was somewhat offset by an increased enrolment in Master's programs and College-based undergraduate programs.



Funding levels: An important question related to Israel's role on the world stage is whether CHE funding levels per student are sufficient. The Committee is of two minds on this question. On the one hand, the Israeli system is generally working well. On the other hand, the Committee was surprised to learn that faculty salaries are well below international competitor levels, which must inhibit faculty recruiting and indicates that the overall amount of funding in the Israeli higher education system is too small. This is an observation that is not specific to BME departments. The Committee thus has concerns about the long-term competitiveness of the Israeli higher education system and recommends that CHE monitor this situation with the medium-term goal of increasing overall funding levels.

2. The Importance of Clear Mission Statements

Because of the breadth of the BME discipline (see above), it is difficult to deliver a teaching program that covers the entire field of BME, and essentially impossible for a single department to cover the entire research field. For this reason, it is important that Departments have a clear understanding of their specific mission. Those who do not run the risk that they will lack critical mass/focus in any single area and thus be so diffuse as to be ineffective. Such a plan should drive departmental growth, if desired. The Committee recognizes that some hiring in the Israeli system must be opportunistic, but as a general comment we strongly recommend that mission statements and strategic plans at the reviewed institutions should be strengthened as a precondition to additional faculty hiring. Additionally, the strategic planning process in each of the institutes would be further enhanced by a nationwide strategic planning process coordinated by the Council for Higher Education; this would allow individual departments to clearly focus on their specific areas of expertise/critical mass, and the Committee recommends that the CHE consider such a process.

3. Programmatic/Thematic Diversity in Israeli Institutions

The Committee observed an appropriate range of programmatic/thematic diversity among the institutions that they visited. Afeka College is very focused on preparing students for the medical device industry. The Technion spans a broader thematic range with notable strength in modern cell-based and biological BME sub-areas. Similarly, Tel Aviv University offers a broad thematic range with close links to Tel Aviv-based industry and hospitals. Ben Gurion University is focused on regional development of talent. In short, each institution has found a niche for their program.

Overall, in view of the size of the State of Israel and the number of students and BME-related companies, the programmatic/thematic diversity appears sufficient. One observation is that the majority of the research that is going on is very device-based and does not fully take advantage of modern developments in bioengineering. This is appropriate for training engineers for industry positions but is not a good long-term strategy since more therapies of a cellular-based nature will begin to emerge on the market. The Committee recommends that programs who wish to take a longer view begin to strengthen cell- and biology-based research and introduce more of this material into the curriculum. This concept is further developed in the Section 6, entitled “Emerging areas of Biomedical Engineering”.

In view of this institutional diversity, one opportunity that Israeli Universities/Colleges may be able to exploit is to allow students from one institution to take a small number of specific courses for credit at another institution. The Committee recommends that this option be explored, optimally with the facilitation of CHE. If used judiciously for a small number of courses (so as to maintain institutional identity and reduce logistical complexity) this could help expose students to a greater diversity of BME topics, particularly at the graduate level. However, the Committee does not recommend the development of an online program in BME. Labs are an important part of a strong BME program and cannot be delivered online, and the committee is unaware of any university outside of Israel that is running a successful online BME program.

4. Research areas that are particularly strong in Israel

Biomedical engineering research areas have a unique position at the intersection between human health, engineering and life sciences. Overall the discipline is broad, with significant potential socio-economic and human health benefits. This means that most researchers in BME departments should

be able to win significant research funding from agencies that support both human health research as well as science/engineering research. As a result, many BME departments around the world are the top grossing units in their respective faculties and universities in terms of the amount of research funding they bring in per faculty member. This is certainly the case in at least one of the institutions we visited, and should be the goal for all other units, i.e. to be the strongest unit in their respective University/College in terms of research funding and research publications.

The committee found that there are 5-6 Israeli researchers who are world-leaders at the international scale in their respective research areas. We specifically identified strong research in tissue engineering, stem cells, biomaterials and biomechanics. This is a particularly good outcome given the size of the Israeli system and the fact that there are ~40 faculty in total in the Departments under review. In fact, the Committee feels that Israel could be regarded as a model for other small-to-medium size countries in terms of the development of their scientific programs in BME.

To continue this leadership trend, the Committee recommends strengthening the relationship between biomedical engineering departments and the Israeli hospitals, since the most current research needs can be best identified in collaboration with clinicians. In addition, we observed that the most successful research laboratories bring a large fraction of their research funding from external sources such as European Research Council, US-Israel Binational Foundation etc. It is thus important to continue to foster international collaborations. CHE may wish to look into establishing specific mechanisms that will foster collaboration and exchange.

5. Emerging areas of Biomedical Engineering

It is clear that research programs at the leading institutions around the world are becoming more "biological". The Committee feels that remaining in strictly "classical" areas of biomedical engineering is a threat to the Israeli system, due to the small size of the Israeli higher education sector, and recommends diversification at the level of the country. Due to the breath of biomedical engineering, it is not possible for every department to have researchers representing all possible areas of biomedical engineering. In fact, too much diversity within each unit would also be a threat, since there would be no critical mass in any particular field. Therefore, we recommend that each unit develops a long term faculty renewal plan that will balance the classical vs. emerging areas within a few specified research foci.

The advantage of continuing to work in classical areas (e.g. biomedical devices, rehab, classical biomaterials) is that clinical impact and clinical translation is likely to occur faster in such areas compared to the translation of biological-based therapies, due largely to fewer regulatory issues. In addition, most industry need is still in classical areas. However, international research reputation and leadership (which is coupled with the ability to win large international team grants) might be easier to achieve within emerging research areas of biomedical engineering

Examples of emerging areas that the Committee finds are being developed around the world are: immunoengineering with particular focus on cancer therapies, engineering of the cancer microenvironment, engineering of stem cell fate, CRISPR/Cas9 gene editing, and microsystems/microdevices with a focus in organ-on-a-chip engineering. Some departments, with enough current research momentum, may consider expanding into these emerging areas.

6. Technology Transfer and Preparing Students for Israeli Industry

Israel is particularly strong in the formation and fostering of startup companies in the medical technology sector, in addition to hosting local facilities of large international companies. This is in part cultural, but also influenced by favorable conditions such as robust government financial support for industry R&D (e.g. MAGNET and NOFAR programs), and several incubator organizations. However, the excellence of the colleges, universities and hospitals plays a crucial role. According to the trade journal *Medical Device and Diagnostic Industry*, Israel has the largest number of medical device patents per capita in the world. This translates into a robust startup community. There are around 1400 medical technology startups in Israel, which per capita is approximately 9 times the number of similarly categorized startups in the USA.

The Committee met several alumni who work in this startup sector, so it is clear that the graduates of Israel's Biomedical Engineering programs are valued. The breadth of knowledge and ability to "translate" from clinicians to product development engineers was often quoted as an advantage that biomedical engineering graduates have over their counterparts in more traditional engineering fields. The alumni working in startups were uniformly supportive of training students in entrepreneurial topics such as regulatory requirements, venture funding, intellectual property and communication skills. Many alumni felt underprepared in this regard, and while some said that they were able to acquire this knowledge on the job, there is value in preparing biomedical engineers who can "hit the ground running." Alumni of programs that teach this material already saw it as hugely valuable and said that it should be required of all students. Students aiming for careers in research also benefit from exposure to this material, as it better prepares them for the day when their research results in a potential product (regardless if that product is based on "classical" or "modern" biomedical engineering research). The Committee therefore recommends that Israeli BME programs maintain or strengthen preparation of students to work in startups as an engine for economic growth and societal benefit.

There is a fair amount of variety in training programs for medical technology entrepreneurship, both globally and in Israel. Individual classes on regulatory issues were already in place at Technion, Ben Gurion and Afeka, and there were two courses (Technion, Ben Gurion) that addressed entrepreneurship more broadly. These courses have proven value, and other global universities have expanded such courses into certificate and Master's programs. There is also a newly established (non-degree granting) program at Hebrew University that is based on the BioDesign program started at Stanford (and currently being copied by several universities in the USA, Europe, and elsewhere). This program takes an approach in which there is considerable effort devoted to needs identification as the initiating step. The Hebrew University program is run out of the School of Computer Science and Engineering, which also offers a PhD degree in bioengineering. It makes use of the expertise of nearly 40 faculty members with expertise in systems biology, tissue engineering, biophysics, bioMEMS, biomechanics, medical devices and bioimaging. This variety of programs indicates that several universities recognize the value of entrepreneurship training, but there is no real coordination or communication among them. The community as a whole would benefit from sharing best practices and general networking of faculty, trainees and students.

The Committee found several instances where faculty were pursuing entrepreneurial activities. University technology transfer policies align well with practices in other countries, but there was some variety in the degree to which entrepreneurial activities were facilitated. Tel Aviv University appeared to have a particularly robust technology transfer process, and several faculty members expressed satisfaction with it. However, the degree to which such activities were recognized as

criteria for tenure and promotion was opaque. This is now a standard component in tenure/promotion processes at leading global universities, and the Committee recommends that Israel should realign its procedures in this regard (see Section 10). Higher education administrators must also assure that robust and productive technology transfer operations are in place.

7. Strong medical schools and hospitals are a good resource for the field in Israel

The three research universities that the Committee visited, Tel Aviv University, the Technion and Ben Gurion University, have formal, solid, and strong ties with internationally leading medical institutions, specifically the Sourasky Tel Aviv Medical Center and Sheba Medical Center (Tel Aviv and Greater Tel Aviv area), RAMBAM (Haifa) and Soroka (Ber Sheva), respectively. Faculty members in all institutions seem to collaborate with medical doctors and other medical professionals in these medical centers, which is extremely important and is an absolute necessity for conducting meaningful, applied research which is beneficial to the society and can lead to advancements in medical technology. The Committee feels that this is a strength of the BME departments in Israeli research universities, and that the Departments and individual professors should continue to strengthen ties with clinicians.

8. Strong students in the Israeli system lead to strong alumni

The students who graduate from the Israeli BME programs move into industry, health care and government, and can serve as very strong ambassadors in each sector. Since the biomed and biotech industries are relatively young, the potential for alumni to have a more substantial impact in these sectors is vast; however, the Committee feels that this network has not generally been well-developed. Thus, we recommend that BME departments realize this potential and invest in developing stronger BME alumni networks. Such networks can serve multiple roles: act as an effective communication channel to industry, as a potential source for donations, and as a resource for academic-industry interaction as related to teaching, research opportunities, and joint research ventures.

9. Promotion Based on Industrial Impact

We note that BME can be a very applied field, e.g. development of a product or device can have a much greater impact on human health than even very high-impact papers. This does not seem to be entirely recognized in the CHE promotion guidelines for Professors and we feel that this is not appropriate.

The Committee thus strongly recommends that the Council for Higher Education include additional metrics for promotion on the regular track which do not primarily depend on publishing research papers, e.g. patents and industrial impact.

10. A Policy Issue for Foreign Students and Post-Docs

We recommend that CHE implement a policy framework that allows foreign postdocs and graduate students to go on maternity leave in a manner similar to that of Israeli citizens.

11. General Comments About Space, Provision of Technical Support and Equipment

All BME Departments that the Committee visited had space problems. In all institutions, the amount of space was too small; further, in some cases, the Department was physically dispersed (inhibiting collegiality and collaboration) or certain labs were run-down. BME Departments present special space challenges: they need an unusual combination of wet and dry lab space, access to animal facilities, and the facilities to mix technology development with traditional biological experiments. Generally, the Committee feels that the quantity and quality of space available to Israeli BME Departments, despite the creative solutions employed by the Departments, is not up to international standards. We recommend that the CHE entertain proposals for funding expansion and/or upgrading of space to allow BME Departments to be more internationally competitive in terms of space provision, which will facilitate recruitment of strong faculty and students.

In a similar vein, the Committee felt that the provision of technical support, through lab technicians and other personnel, was below international standards; in some cases, it was markedly below international standards. (This is a comment about the number, not the quality, of personnel.) We recommend that the CHE entertain proposals for hiring of additional support personnel, which will leverage investments in faculty, students and infrastructure and allow BME Departments to be more internationally competitive.

Finally, we recommend that BME Departments give more consideration to creation of Core Facilities within their department. This is standard practice in international BME Departments and seems to be less-used in Israel; there are potential cost and efficiency benefits from such facilities. The Committee notes that these savings can only be realized if there is strong technical support in place (see previous paragraph).

12. Unique Aspects of the Israeli Higher Education System

The Committee recognizes that Israeli students are different from their American and European peers in that most of them reach the higher education system at an older age, after serving in the army or in national service. Some even have families at the undergraduate phase and many have families with children in their graduate phase. Hence Israeli students are typically more responsible, and are efficient and motivated to complete their course of studies on time. This is beneficial in terms of their ability to cope with difficulties and their level of maturity and mental strength. The Committee had the impression that Israeli students, in all of the institutions which were evaluated, are extremely motivated and take their studies and research (at the graduate level) very seriously. This is a strategic advantage of the Israeli system.

13. Joint BME/MD Degree Programs

The Committee was impressed with the joint BSc/MD program at the Technion and considered whether this program should be established at other universities. The Committee felt that this is a highly specialized track that, by definition, will attract a small cohort of very elite students. There is likely an insufficient student talent pool to run viable similar programs at multiple universities, and therefore the Committee does not recommend this program be established at other universities.

On the other hand, MD/PhD programs are successful at many international leading institutions, and Israeli universities may wish to consider the establishment of such programs.

November 2016

Prof. C. Ross Ethier

Department of Biomedical Engineering

Georgia Institute of Technology & Emory University School of Medicine

USA

Dear Professor,

The Israeli Council for Higher Education (CHE) strives to ensure the continuing excellence and quality of Israeli higher education through a systematic evaluation process. By engaging upon this mission, the CHE seeks: to enhance and ensure the quality of academic studies, to provide the public with information regarding the quality of study programs in institutions of higher education throughout Israel, and to ensure the continued integration of the Israeli system of higher education in the international academic arena.

As part of this important endeavor, we reach out to world-renowned academicians to help us meet the challenges that confront the Israeli higher education by accepting our invitation to participate in our international evaluation committees. This process establishes a structure for an ongoing consultative process around the globe on common academic dilemmas and prospects.

I therefore deeply appreciate your willingness to join us in this crucial enterprise.

It is with great pleasure that I hereby appoint you to serve as the Chair of the Council for Higher Education's Committee for the Evaluation of the study programs in Medical and Bio-Medical Engineering. In addition to yourself, the composition of the Committee will be as follows: Prof. James Moore, Prof. Milica Radisic and Prof. Amit Gefen.

Ms. Alex Buslovich-Bilik will be the coordinator of the Committee.

Details regarding the operation of the committee and its mandate are provided in the enclosed appendix.

I wish you much success in your role as the Chair of this most important committee.

Sincerely,

Dr. Rivka Wadmany

Vice Chair,

The Council for Higher Education (CHE)

cc: Dr. Varda Ben-Shaul, Deputy Director-General for QA, CHE

Ms. Alex Buslovich-Bilik, committee coordinator

Schedule for the Evaluation of Medical and Bio Medical Engineering

November/December 2016

Time	Visit/Meeting	Location	Accommodation
Sunday **November 27th**	Preparation Meetings 10:00-18:00	*Dan Panorama Tel Aviv*	*Dan Panorama Tel Aviv*
Monday **November 28th**	Afeka Academic College	*Tel Aviv*	*Dan Panorama Tel Aviv*
Tuesday **November 29th**	Preparation and writing meetings	*Tel-Aviv*	Dan Carmel Haifa
Wednesday **November 30th**	Technion	*Haifa*	Dan Carmel Haifa
Thursday **December 1st**	Preparation and writing meetings	*Haifa*	Dan Panorama Hotel Tel Aviv
Friday **December 2nd**	Preparation and writing meetings	*Tel Aviv*	Dan Panorama Hotel Tel Aviv
Saturday **December 3rd**	Day off	*Tel Aviv*	Dan Panorama Hotel Tel Aviv
Sunday **December 4th**	Tel Aviv University	*Tel Aviv*	Dan Panorama Hotel Tel Aviv
Monday **December 5th**	Preparation and writing meetings	*Tel Aviv*	Dan Panorama Hotel Tel Aviv
Tuesday **December 6th**	Ben Gurion University	*Beer-Sheva*	Dan Panorama Hotel Tel Aviv
Wednesday **December 7th**	Writing and summation meetings	*Tel Aviv*	Dan Panorama Hotel Tel Aviv