Biomedical engineering curricula: trends in Australia and abroad

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ABSTRACT: This article provides an analysis of representative biomedical engineering curricula in Australia, the USA and the UK. The research was undertaken as part of an Australian Learning and Teaching Council project on Australian dual degrees. The findings suggest that biomedical engineering offerings in the United States tend to treat biomedical engineering as a separate discipline in itself, with distinct methodological and analytical techniques. Many universities in the United Kingdom offer courses specifically in medical engineering and/or biomedical engineering made up of core engineering subjects together with specialist biomedical engineering subjects or medical engineering subjects. A limited number of Australian universities offer degrees specifically in biomedical engineering. Australian dual degrees tend to offer standard engineering subjects alongside standard medical science subjects, and the structure can prevent students from choosing subjects that specialise in the area of biomedical engineering. It can be concluded that Australian dual degrees can be a poor choice for students who wish to progress in the field of biomedical engineering.

INTRODUCTION

This article provides an overview of recent international curriculum developments in tertiary biomedical engineering programmes and maps these against developments in Australia, in particular focussing on the dual degree models that have become so popular in Australia as compared to elsewhere. There are a number of key issues central to research in this field - the need to integrate knowledge from different disciplines in ways that match real-world requirements in this burgeoning industry; the tensions inherent in finding a balance between core and specialist knowledge allowing for adequate breadth and depth of coverage in biomedical engineering subject areas, and the ongoing need to appraise and renew curricula in response to fast-paced emerging technologies, without diminishing standards. One of the research questions was whether structuring biomedical engineering education within dual degrees has been a successful approach. This research arose from concerns about whether the combined discipline areas are satisfactorily integrated, sufficiently focussed on outcomes related to the biomedical industry, and whether current offerings are too locked into pre-existing units of study within each of the disciplines.

Previous studies concerned with the development of biomedical engineering curricula, some of which are comparative in nature, have identified in particular the importance of engaging students in interdisciplinary research, and problems associated with combining subjects from different disciplinary areas into an integrated curriculum [1-3]. Slaaf and van Genderen [3] report a case study involving Eindhoven University of Technology, which traces the development of biomedical engineering from a small cross-disciplinary programme into a new discipline *with its own methods, and ways of analysing and thinking* [3]. A study of biomedical engineering in the UK lists the biomedical engineering degrees available in the UK in 2006-2007 [4]. This study put the value of the medical engineering industry worldwide at £50 billion and, concurrent with the growth that had taken place in this industry, there has been large enrolment increases in subjects allied to the medical industry.

It has been previously suggested that there exists a tension between equipping students with the tools and methodologies required by industry and facilitating true deep learning that will enable graduates to contribute as educated members of society [5][6]. Concerns regarding job-readiness appear to be a significant motivator for students enrolling in engineering dual degrees [7]. According to Welsman, *choosing a double-degree likely reflects student awareness of career market expectations and their need for competitive edge* [8]. It is thought that dual degrees combining engineering with business, commerce, management, arts, science and medical science have been seen to be attractive to students largely through a perception of broader scope and potentially increased career options [9][10]. There is also a perception among students that employers are more likely to employ graduates who have skills that cross more than one disciplinary area [10][11]. Dual degrees are thought to present particular problems for engineering students who wish to specialise in biomedical engineering. One of the problems arises from the fact that certain chains of subjects and sub-majors in niche areas are not available to students of dual degrees. This is especially concerning

because sub-majors are the only avenue available for students of some degrees to specialise in areas such as biomedical engineering and robotics [12][13].

METHOD

This research was undertaken as part of an Australian Learning and Teaching Council (ALTC) project that investigated concerns regarding Australian dual degrees. A goal of this part of the research was to investigate aspects of biomedical engineering curricula in Australia and abroad. Some of the findings arise from surveys of a sample of 30 employers of engineering graduates. These employer organisations were drawn from employer networks of four Australian universities: Curtin University, Queensland University of Technology, RMIT University and the University of South Australia. The surveyed organisations included a range from small businesses to large companies. The survey interviewers asked open ended questions concerning the employers' experiences of graduates of dual degrees, the employers' expectations regarding integrative abilities, the expertise of the graduates, views on dual degrees, and the employment prospects of dual degree students. Other findings arose from direct analysis of a selection of university course offerings in areas relevant to biomedical engineering, including an analysis of the relevant courses of each of the five Australian Technology Network universities.

FINDINGS

The spread of the curricula across different disciplines is variously described as multidisciplinary, interdisciplinary or transdisciplinary education. Such terms emphasise a focus on real world needs, and secondly to emphasise, the diverse employment options available to students on completion. MIT's programme, for example, prepares students for careers in biological and biochemical sciences and also in medicine, law and financial analysis. UTS offers a combined Bachelor of Engineering/Medical Science degree programme with future careers identified across a broad spectrum, including biotechnology, communications, construction, mathematical modelling, nanotechnology and transportation. Examples of biomedical engineering programmes available in three Australian and three overseas universities are given in Table 1.

Table 1: Example biomedical engineering programmes available in Australian and overseas universities.

Country	University	Programme	Years	Stated course objectives or employment options
Aus	UNSW	Concurrent BE/MBE	5	Design of medical instrumentation and prostheses; involvement in development, manufacture and testing of medical products; and the management of technology in the hospital system [14].
Aus	University of Sydney	BE (Mechanical (Biomedical))	4	Managing life-support equipment in a hospital; working in a product development team for a new joint replacement device in a biotechnology company [15].
Aus	University of Sydney	Combined BE/BMedSc Engineering specialisation in Biomedical Engineering	5	All career options listed for engineering graduates plus government departments, private practice, consulting firms, research, construction companies, design, development, planning and marketing.
Aus	QUT	Bachelor of Engineering (Medical)	4	Advisor to health and medical professionals, working in a firm concerned with the design, manufacture, supply and maintenance of medical, health and sporting equipment or an occupational health agency or in a research institution [16].
Aus	UniSA	Bachelor of Engineering (Biomedical)	4	The programme aims to prepare students for professional careers in engineering and medical science and develop skills to investigate, plan, design manufacture and maintain systems and equipment used in all aspects of health care [17].

Aus	UTS	Combined BE/BBiotech	5	Career in biotechnology, materials technology, medical technology and instrumentation, molecular biology and nanotechnology. Good employment opportunities exist with government scientific organisations, in research in universities, hospitals and industry, and in specialised development and consulting companies 18].
Aus	UTS	Combined BE/BMedSc	5	Positions in biotechnology, communications, construction, energy and resource exploration and development, environmental protection and management, materials technology, mathematical modelling, medical technology and instrumentation, molecular biology, nanotechnology and transportation [19].
USA	MIT	BE/SB (Biological Engineering/BSc)	4	As the field of biological engineering expands, biotech, pharmaceutical, and medical device companies increasingly look to MIT, whose engineers have a solid foundation in both biological and biochemical sciences. The programme also prepares students for graduate school and careers in research, medicine, law, and financial analysis [20].
USA	Johns Hopkins	BSc (BME)	4	Basic and applied research in engineering, biology or medicine at universities, government laboratories, and large industries in an area of biomedical science or engineering. Professional engineering practice - working in industrial settings, hospitals or other biomedical institutions, these graduates use multiple facets of science to pursue industrial jobs in biomedical engineering. This includes engineering by research and development, engineering design and product development, and business aspects of engineering, such as sales, customer engineering and technical management [21].
USA	Johns Hopkins	BA (BME)	4	
USA	Johns Hopkins	BS/MS (BME)	4	
UK	Imperial College	BE Biomedical Engineering	3	Design and development within small bio-engineering companies, medical physicist or bio-engineer within a hospital. Significantly Imperial College writes that on completion of the degree students do not need to work in biomedical engineering or engineering. *Their skills are transferable across a range of careers – banking, commerce, sales and marketing within BioEngineering* [22].
UK	Imperial College	ME Biomedical Engineering with specialisation in Electrical Engineering or Mechanical Engineering	4	

In the United States, these programmes are often built around a multi-disciplinary or interdisciplinary framework with an emphasis on problem-based learning and industry placements, designed to equip students with the skills for an expanding and rapidly changing industry. For example, a key component of Johns Hopkins University's undergraduate programme is the Design Team course, which focuses on the design of medical instruments to solve problems identified by the biomedical engineering industry.

Biomedical engineering offerings in the United States appear to have reached a state of maturity where the multiple disciplines are essentially treated as a new, single discipline. A consequence of this is that the discipline is regarded as having distinct methodological and analytical techniques. Significant growth has been seen in biomedical engineering education in the United States, and the United States provides a large proportion of the world's biomedical engineering employees.

Universities in the United Kingdom offer courses specifically in medical engineering and biomedical engineering. These courses are ordinarily made up of core engineering subjects together with specialist biomedical engineering subjects or medical engineering subjects. This is in contrast to the United States, which has increasingly less emphasis on core units and more emphasis on specialist aspects of biomedical engineering.

A relatively small number of Australian universities offer degrees specifically in biomedical engineering. Those that do include the University of South Australia, which offers a Bachelor of Engineering (Biomedical) and Queensland University of Technology, which offers a Bachelor of Engineering (Medical). These Australian degrees are made up of core engineering subjects together with specialist biomedical engineering subjects or medical engineering subjects. Students at other universities are generally able to elect biomedical engineering as a *sub-major* as part of an engineering degree.

It would seem Australian dual degrees are not a good option for students who wish to specialise in biomedical engineering. The dual degrees generally do not provide sufficient scope for electives including biomedical engineering sub-majors. For example, the UTS BE/BMedSci dual degree offers standard engineering subjects alongside standard medical science subjects, and the structure of the dual degree does not permit students to undertake a sufficient number of specific biomedical engineering subjects. In addition, the inability to choose sub-majors may make it particularly difficult for dual degree students to traverse pathways into postgraduate research - this is because the sub-majors in the corresponding single degree programmes in some cases provide the only path to specialise in biomedical engineering.

Table 2: Summary of findings.

Biomedical engineering	Summary of findings
United States	Many of the biomedical engineering offerings in the United States have reached a state of maturity where the discipline is essentially treated as a new discipline with distinct methodological and analytical techniques - examples are MIT and Johns Hopkins University. Significant growth has been seen in biomedical engineering education in the United States.
United Kingdom	Universities in the United Kingdom offer a range of degrees specifically in medical engineering and biomedical engineering. These degrees are made up of core engineering subjects together with specialist biomedical engineering subjects or medical engineering subjects.
Australian single degrees	A limited number of Australian universities offer specific degrees including UniSA, which offers a Bachelor of Engineering (Biomedical) and QUT, which offers a Bachelor of Engineering (Medical). The degrees are made up of core engineering subjects together with specialist biomedical engineering subjects or medical engineering subjects. Students at other universities are generally able to elect biomedical engineering as a *sub-major* as part of an engineering degree.
Australian dual degrees	Australian dual degrees generally do not provide sufficient scope for electives including biomedical engineering sub-majors. Hence, dual degrees can be a poor choice for students who wish to progress in the field of biomedical engineering. For example, the UTS BE/BMedSci dual degree offers standard engineering subjects alongside standard medical science subjects, and the structure of the dual degree does not permit students to undertake a sufficient number of specific biomedical engineering subjects.

DISCUSSION

In the United States, biomedical engineering education evolved in response to emergent industry needs with direct industry input in programmes developed within leading universities, including Johns Hopkins University. The United States Whitaker Foundation, established in 1975 to support interdisciplinary work between medical science and education, focussed its funding efforts from 1992 on assisting institutions to set up departments and programmes specialising in biomedical engineering, again in response to the growing needs of this area [23]. Consultation between educational institutions and local biomedical industries may go some way towards explaining the diverse approaches to the structure and emphasis of undergraduate degree programmes as they respond to local conditions. Such consultations influence ways that relevant biomedical engineering industry participants and university programmes have an impact on the future growth and direction of the local industry. The National Academy of Engineering, arguably the relevant peak US engineering body, indicated in the 2005 Phase II report that the engineering curriculum must build ties with industry and adopt interdisciplinary approaches [24]. The US government and funding agencies have directly linked the growth of new industries to education and more specifically to multi-disciplinary education. The National Science Foundation (NSF) has targeted funding toward multidisciplinary programmes, while the America Competes Act (US Congress,

Public Law 110-69-Aug. 9, 2007 Section 7007 Interdisciplinary Research) made the National Science Board (NSB) responsible for ensuring that the NSF was successful in engaging undergraduate students in *research experiences in interdisciplinary settings*. These documents emphatically stress the need for hands-on research and acknowledge that real world problems are not contained within disciplinary lines [2].

This stands in stark contrast to recent policy initiatives and reports in Australia. The Bradley Review of Higher Education for example, remains very much within the framework of disciplines and does not engage with the need for multidisciplinary, interdisciplinary or transdisciplinary programmes in its calls for educational reform [25]. In Engineering Australia's 2009 report, *The Engineering Profession: A Statistical Overview,* biomedical engineering is categorised under *Other* in the enrolment statistics for undergraduate programmes despite a significant increase in numbers and percentage share of students in the *Other* category [26]. This is a concern in a country such as Australia where there are signs that the biomedical industry is unable to reach the critical mass required to compete on the international stage. It is now two decades since a review conducted by Price Waterhouse into the Australian scientific/medical equipment industry concluded that, at less than 1% of a worldwide industry, it was in major need of expansion. Without a strong response from Australia's leading educational institutions it is arguable that it will remain underdeveloped.

In some ways, educational issues relating to biomedical engineering can be understood within the paradigm of Mode 2 knowledge put forward by Gibbons et al [27]. Mode 2 knowledge emerges out of four inter-related processes. They are: the emergence of more open systems of knowledge production, which are not confined to disciplines and, which are characterised by two-way interaction rather than the former one-way direction of science to society; a re-contextualisation, where those outside the institution assume a role in the production of knowledge; the emergence of *socially robust* forms of knowledge, where negotiations over both the questions to be raised and the answers take place outside the institution; and the distribution of expertise across institutions and the public domain connecting knowledge to decision making and seeking knowledge, which can be applied in the public domain [28].

The findings of this project are broadly consistent with findings reported by Lithgow in 2001 concerning a comparison of biomedical programmes in the United States and Europe. Lithgow, however, concluded that new areas need to be developed such as biomedical engineering systems modelling, and cellular and tissue engineering to make the curriculum relevant to the global marketplace. He asked whether it was possible to *make the curricula compatible with global trends and expectations* [29]. Similar findings have been reached by research on methods for improving safety in engineering. However, some other research has concluded that a greater emphasis on developing skills in working in multidisciplinary teams may be preferable to attempting to produce graduates that are skilled in multiple disciplines [30]. This is consistent with the United States approach of tending to treat biomedical engineering as a new discipline, and not treating it as an intersection of two or more pre-existing disciplines.

This is a particular concern with Australian dual degrees. Students might ordinarily expect a dual degree that combines engineering and medical science would assist in developing the highly specialised niche areas that exists at the intersection of the two disciplines. However, it has been reported that *the undergraduate programs in the two disciplines have tended to remain completely separate* [31]. Thus, it appears that attempts by dual degrees to integrate two disciplines can be less than successful. In particular, some of the dual degrees that attempt to encompass biomedical engineering do not seem to offer much that specifically relates to biomedical engineering.

CONCLUSIONS

Overall, the findings suggest that biomedical engineering offerings in the United States tend to treat biomedical engineering as a separate discipline in itself, with distinct methodological and analytical techniques. Universities in the United Kingdom offer courses specifically in medical engineering and biomedical engineering, and these courses tend to be made up of core engineering subjects together with specialist biomedical engineering subjects or medical engineering subjects. A limited number of Australian universities offer specific degrees in biomedical engineering. Australian dual degrees, on the other hand, tend to offer standard engineering subjects alongside standard medical science subjects, and the dual degree programmes tend to prevent students from choosing subjects that specialise in the area of biomedical engineering. This being the case, Australian dual degrees appear to be a poor choice for students who wish to progress in the field of biomedical engineering.

ACKNOWLEDGEMENT

This work was undertaken with the assistance of an Australian Learning and Teaching Council Competitive Grant.

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