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Abstract: Cardiff University has offered a medical engineering undergraduate programme since 2001 and hence delivers one of the longest-running and most established medical engineering programmes within the UK. It currently offers BEng (Hons) and MEng (Hons) programmes that are both accredited by the Institution of Mechanical Engineers and include the option to undertake a year in industrial employment. The admissions policy ensures that the intake consists of a diverse range of students and is typically very successful in attracting female students.

The programmes consist of six key academic threads which ensure that the content is both relevant and continuous, with all threads tailored to provide a patient-focused learning environment. Students initially learn core and fundamental principles in years 1 and 2, supported by a range of laboratories and practical experimentation. The latter years then encourage the students to corroborate and apply this knowledge, including involvement in a range of project-based learning exercises. The programme is delivered by a core of experienced academic medical engineers, with support from other engineering colleagues, as well as colleagues from the School of Biosciences, the School of Medicine, and the National Health Service. Thus, the programme delivers a wide range of modules which guarantee that graduating students have a thorough understanding of all possible career options. These two factors are significant in making it possible for students to follow their chosen career path upon graduation.

Keywords: medical engineering, Cardiff University, undergraduates

1 INTRODUCTION

Cardiff University is a Russell Group university with approximately 20 000 undergraduate students and is ranked within the world's top 100 Higher-education institutions [**1**]. As Cardiff School of Engineering has been offering a 3 year BEng (Hons) and a 4 year MEng (Hons) undergraduate programmes in Medical Engineering since 2001, both are now well established. As per the framework for higher education qualifications (FHEQ) in England, Wales, and Northern Ireland, the BEng (Hons) programme is a first-cycle qualification (FHEQ level 6) and the MEng (Hons) programme is a second-cycle qualification (FHEQ level 7) [**2**].

A market was identified for an undergraduate medical engineering programme that would build upon both the School's medical research group and the thriving postgraduate degrees (MSc Clinical Engineering and MSc Orthopaedic Engineering) [**3**]. The Medical Engineering degree programmes were established within the Systems Division of the School of Engineering and were modelled on the successful Integrated Engineering degree programmes. These programmes consist of a combination of modules drawn predominantly from within the Mechanical Engineering and the Electrical and Electronic Engineering disciplines. Consequently, the undergraduate Medical Engineering programmes were developed to consist of key elements principally from Mechanical Engineering, complemented

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by a medically oriented knowledge with delivery supported by the neighbouring University of Wales College of Medicine (UWCM). The Institution of Mechanical Engineers (IMechE) accredits both undergraduate programmes, with the MEng degree meeting the full *UK standard for professional engineering competence* (UK-SPEC) academic content for chartered engineers [**4**].

Subsequent restructuring within the School of Engineering has seen the Medical Engineering degree programmes now being administrated within the new Mechanical, Medical, and Integrated Engineering discipline. In addition, Cardiff University has merged with UWCM, creating the School of Medicine (within Cardiff University), benefiting the Medical Engineering degree programmes by formalizing the delivery of some content by clinical-based colleagues.

2 ADMISSIONS

Cardiff University delivers programmes for both BEng (Hons) Medical Engineering and MEng (Hons) Medical Engineering [**5**], with typical A-level offers of BBC (BEng) and ABB (MEng) including a minimum grade B in Mathematics.

The number of applications received to study on the Medical Engineering programmes peaked at 97 for the 2007 intake, with overseas students comprising approximately one third of all applicants. Applicants are typically more attracted to the MEng (Hons) than to the BEng (Hons) programme. Conversion rates within Medical Engineering are the highest of all those within the discipline, and hence the intake is capped typically at approximately 25 students per academic year to avoid logistical issues when running specialist laboratory sessions and site visits. The attraction of the programme to female students ensures that the cohort is typically evenly balanced with regards to gender, and peaking when the 2007 BEng (Hons) intake consisted of 67 per cent female students.

All students must have either studied A-level Mathematics or achieved equivalent academic standards at other qualifications (e.g. Scottish Highers or International Baccalaureate) to be accepted on to year 1 of either programme. Home students who do not have an appropriate mathematics qualification can undertake the Foundation Year, which provides the necessary skills and knowledge in a broad spectrum of engineering principles to progress directly to year 1 of an engineering degree programme. International students in a similar position can undertake the University-run International Foundation Programme in Engineering. Students with sufficient previous knowledge can also, where appropriate, enter directly into year 2 of study.

The Medical Engineering programme also offers the students the possibility of including a 'sandwich' year in industry. This allows the students to work for 1 year (between years 2 and 3), with successful completion resulting in the awarding of a City & Guilds Licentiateship qualification and recognition of the training received, as recorded by the IMechE-accredited monitored personal development scheme. Considering the current academic year, there are seven students on an industrial placement working either for specialist medical engineering companies or within the medical engineering division of larger multi-national companies.

3 PROGRAMME STRUCTURE

As with other degree programmes within the School, the first 2 years of both the BEng (Hons) and the MEng (Hons) programmes are identical. Bifurcation at the end of year 2 depends on the average mark obtained by a student. Those students with a minimum year 2 average mark of 60 per cent can undertake the MEng programme, while all others will undertake the BEng programme. Additionally, the programmes have been designed to allow students to acquire knowledge over a broad spectrum of medical engineering areas, ensuring maximum vocational opportunities within the medical engineering sector upon graduation; the students also have the opportunity to follow one of the many other career pathways available to similarly highly numerate graduates.

The majority of year 1 of Medical Engineering is common to the other programmes within the discipline (i.e. Mechanical Engineering and Integrated Engineering); the Medical Engineering programmes then becomes increasingly specialized in subsequent years. Students can transfer into or out of Medical Engineering to or from other programmes within the discipline at the end of the first semester; transfers at a later stage and to other disciplines are dealt with on an individual basis.

Because of the multi-disciplinary nature of the Medical Engineering programmes, a number of 'threads' have been established to ensure that the delivered content is both continuous and relevant. The six key threads that have been identified are as follows: Biosciences (Anatomy, Physiology, and Relevant Biochemistry); Fundamental and Applied Mechanical Engineering; Mathematics; Electronic

Engineering and Computing; Design, Materials, and Manufacture; Professional Studies. The content of each of these key threads have been designed ultimately to present programmes which provide a patient-centred engineering-oriented learning experience. As such, the programmes incorporate some medically focused elements within traditional engineering modules as well as specialist medical and clinical modules, while maintaining a core of mechanical and electronic engineering principles.

Years 1 and 2 of the Medical Engineering programme predominantly consist of the learning of theoretical concepts delivered by lecture, with this knowledge being supplemented by tutorials, presentations, laboratory sessions, and practical workshops. In addition to further theory in years 3 and 4 (the latter year only when studying for a MEng degree), students also apply and corroborate the knowledge and understanding gained from across all threads. In year 3, this is achieved most notably during the 30-credits individual project, which sees the student undertake individual guided research. This project is undertaken in year 3 to ensure students who do not complete the MEng (Hons) programme can obtain an accredited BEng (Hons) degree. Two 20-credits multi-disciplinary group projects in year 4 draws upon the teamwork, organization, and project-management skills acquired throughout the other years of study. The first project, which is also offered to Mechanical Engineering and Integrated Engineering students, requires the development and validation of an instrumented paediatric automotive test dummy to obtain accurate data from traumatic incidents. The second project is offered across the entire School of Engineering (i.e. including the disciplines associated with Electrical and Electronic Engineering and with Civil Engineering) and requires the design of a hospital in collaboration with international consulting engineers Ove Arup, with the need to consider all design requirements and constraints.

The Medical Engineering programme benefits from content being delivered both by experienced academic medical engineers, supplemented by specialist colleagues from a broad spectrum of disciplines. These personnel are drawn from the School of Engineering, the School of Biosciences, and the School of Medicine within Cardiff University, as well as a variety of industries and the Cardiff and Vale National Health Service (NHS) Trust. Importantly, this structure and experience ensures that the students experience the desired patient-centred engineering-oriented learning environment.

4 PROGRAMME CONTENT

The UK academic system differs from the European Credit Transfer System (ECTS), with 10 credits being equivalent to 15 ECTS credits. As per the Credit and qualifications framework for Wales [**5**] the MEng (Hons) course consists of 480 credits, whereas the BEng (Hons) consists of 360 credits. The 120 credits taught each year are structured around a framework consisting of six key threads. This framework, as indicated by the thread diagram (Table 1), ensures that the programme content remains both continuous and relevant.

4.1 Biosciences

Students benefit from the close links between the School of Engineering and the School of Biosciences, enabling a hands-on experience when learning the fundamentals of human anatomy, physiology, and relevant biochemistry. Experimental laboratories exploring the cardiovascular and nervous systems supplement lectures, while the students also spend a number of sessions in the cadaveric dissection room; key aspects of physiology are also taught within the Electricity in the Human Body module. This knowledge is then incorporated and forms the foundation of a number of modules delivered as part of the Design, Materials, and Manufacture thread and the Fundamental and Applied Mechanical Engineering thread.

4.2 Fundamental and Applied Mechanical Engineering

Mechanical Engineering forms the core of the Cardiff University Medical Engineering undergraduate degree programmes. In the first semester of year 1, the students are taught Thermodynamics and Fluid Mechanics, and Mechanics. The former module enables the students to learn the fundamental fluid mechanic and thermodynamic principles of liquids and gases. These principles are developed further in year 2, with students learning the properties of gases, and the principles and relationships of liquids and vapours. Students are then in a position to apply this knowledge in year 3 (and year 4) in a number of patient-oriented situations, e.g. by using computational fluid dynamics to explore blood flow, measuring respiration rates during exercise, or investigating the principles of gaseous and/or intravenous anaesthesia. For those students studying the MEng (Hons) programme, year 4 offers additional opportunities to

Table 1 The thread diagram for undergraduate programmes in Medical Engineering

	Modules for the following key threads					
Semester	Biosciences	Fundamental and Applied Mechanical Engineering	Mathematics	Electronic Engineering and Computing	Design, Materials, Manufacture	Professional Studies
Year 1						
Autumn		Mechanics 1* Thermofluids 1*	Engineering Analysis 1*	Network Analysis*	Engineering Applications‡	Professional Development and Communication*
Spring	Anatomy and Physiology*	Mechanics 2*	Engineering Analysis 2*	Computing*	Material and Manufacture*	
Year 2						
Autumn	Electricity in the Human Body*	Solid Mechanics* Biomechanics*	Engineering Analysis*		Materials and Manufacture* Design‡	
Spring		Control and Instrumentation* Dynamics* Thermofluids 2*		Electronic Engineering*		Introduction to Law, Accounting, and Economics*
Year 3						
Autumn		Fluid Mechanics† Biomechanics†		Electronic Engineering 1* Microprocessors and Instrumentation Systems†	Individual project§	Business Management* Clinical Engineering*
Spring		Solid Mechanics† Fluid Power Control†			Clinical Engineering 3* Engineering applications* Orthopaedic and Rehabilitation Engineering*	
Year 4						
Autumn		Sports Biomechanics*		Digital Medical Processing*	'Medical' group project‡ 'Integrated' group project‡	Case study* Forensic Bioengineering*
Spring		Fluid Mechanics† Control†	Medical Ultrasound* Applied Numerical Methods in Engineering†		Quality and Reliability†	Management in Industry*

*10-credit core (i.e. compulsory) module.
†10-credit optional module.
‡20-credit core module, spanning both semesters.
§30-credit core module, spanning both semesters.

apply this knowledge to a clinical environment during the hospital design project (e.g. the supplying of clean air to operating theatres).

The Medical Engineering students are also taught 10-credit modules in Mechanics in each semester of year 1, learning the principles of Statics, Solid Mechanics, and Dynamics. Within the Dynamics element, the students learn to analyse motion of a particle as well as motion of a rigid body. Within the Statics and the Solid Mechanics elements, the students learn to solve statically determinate and indeterminate engineering problems and gain an understanding of solid elastic materials. The knowledge gained from all these elements forms the fundamental principles of the more specialist year 2 modules in Solid Mechanics and Dynamics respectively. This knowledge is then applied to the human body in the Biomechanics 1 module and developed further in the Biomechanics 2, Sports, and Forensic Biomechanics Modules in later years.

4.3 Mathematics

The Medical Engineering programmes also have a strong mathematical core, in line with the standards expected of IMechE-accredited engineering programmes. In the week preceding the start of their first academic year, all engineering students at Cardiff University are required to sit a multi-choice mathematics examination; this is in recognition of

the importance of mathematics to any engineering discipline and serves to ensure appropriate targeting of additional resources. By the end of the first semester, students should have learnt the basics of calculus and by the end of the second semester they should understand the scope offered by numerical techniques for the solution of typical engineering problems. Advanced mathematics is then taught in the first semester of year 2, following which the students are expected to have the required knowledge, skill, and understanding to apply the relevant mathematical technique to the particular engineering scenario. For example, within the Control and Instrumentation module, students have to apply Laplace transforms and transfer functions within a common medical environment requiring a control system. Mathematics skills are then drawn upon in the Medical Ultrasound module (year 4).

4.4 Electronic Engineering and Computing

Medical Engineering students are introduced to the concepts of electrical and electronic engineering during their first semester in Cardiff, undertaking a 10-credit module (Network Analysis) that introduces the basic techniques and methods used to analyse linear electrical circuits. These skills are developed in year 2 with an introduction to the principles of analogue and digital electronics. Student learning is then consolidated in year 3 Electronics module, with an optional module in Microprocessors and Instrumentation available to students to supplement their earlier learning of Computational Programming. This skill set is then applied to a medically oriented environment, most notably in the Digital Medical Microprocessors module, for instances of physiological measurement. The former explores the excitable cell and the generation, conduction, and correction of action potentials within the human body, while the latter explores the use of microprocessors to obtain and analyse data effectively from human subjects.

4.5 Design, Materials, and Manufacture

Medical Engineering students are taught a total of 20 credits of materials science in their first 2 years at Cardiff. The first of these modules introduces the students to the importance of the crystal structure on common polymers and ceramics; the students also learn how to describe the main characteristics of manufacturing processes, while also gaining an understanding of the selection and use of materials in medical engineering design.

In line with IMechE accreditation, the students are also required to perform practical examples to supplement their understanding of a variety of modules. In year 1 the students complete a range of laboratory experiments that provide an appreciation of the fundamental engineering principles as well as a structured series of workshop practice sessions, including health and safety, while the relevant principles tend to be applied in the year 2 laboratories. Students are also introduced to all aspects of design including drawing, computer-aided design, and product design in year 1. This module culminates in the design, make, and test (DMT) activity, a compulsory week devoted to a project immediately post-examinations. During the DMT activity the students are required to provide a design to a given specification, to manufacture it, and then to demonstrate its functionality in open competition. These skills are enhanced throughout the Design, Materials, and Manufacture thread and during a number of associated modules throughout their university career. In particular, the 20-credit Design module in year 2 offers students the opportunity to perform both a detailed product design and an in-depth mechanical design exercise; this culminates in a design project where the students have to work alongside industrial collaborators to seek an engineering solution to a clinical problem.

In addition to the continued development of general design skills, students in year 3 are also introduced to the Medical Device Direct, the legislation that governs the certification of all medical devices, including all ethical aspects. Students are also required to perform some individual research in the individual project, which commonly relies upon the ability to design and/or develop an experimental apparatus. Design skills are further enhanced when considering assistive technologies in Orthopaedic and Rehabilitation Engineering and are consolidated with all other knowledge during their involvement with the two multi-disciplinary group projects in year 4.

4.6 Professional Studies

The students are also taught at least one Professional Studies module per academic year. In year 1, they are introduced to the importance of planning their career pathway, including involvement with the relevant professional bodies. In year 2, students

learn the fundamental skills required by an engineer with respect to accounting and management. These general engineering management skills are developed further in years 3 and 4, while also learning knowledge specific to the medical engineer. In particular, the students gain an insight into life within Clinical Engineering, having meetings with current trainee clinical scientists in addition to touring the local NHS facilities; subsequently the students can make an informed career choice. Additionally, students obtain an appreciation of the law pertaining to the practice of a medical engineer including elements of English and European legal systems, civil law, crimical law, alternative dispute resolution, and the engineer as an expert witness in the Forensic Bioengineering module.

5 CAREER PROSPECTS

Students graduating from the Medical Engineering undergraduate programme tend to follow similar career pathways to those from the Mechanical Engineering Programme, i.e. further study, aligned-industrial employment, or unaligned-industrial employment. Evidence suggests that approximately one half of the students graduating from the BEng (Hons) programme opt for further study (typically to M level), probably to achieve the required UK-SPEC academic standards for chartered engineer status [**4**]. Typically, this group of students either have not met the academic threshold for progression to the MEng programme or alternatively wish to follow a career path that would benefit from the attainment of a specialist higher degree (e.g. MSc in Tissue Engineering); this includes the option of the 4 year degree in Medicine at Swansea University. Some graduates, from both the BEng and the MEng programme, have progressed directly to read for a related PhD, within the School or elsewhere, while others have successfully obtained a post on the highly competitive trainee clinical scientist scheme.

A significant proportion of graduates move into the medically related industry, with orthopaedic design companies probably representing the most likely industrial career pathway. Students have also been known to move into medically associated industries, e.g. by working within the defence sector. As with all engineering degree programmes, a minority of students decide to follow a career pathway that is unrelated to the discipline, either through a predetermined decision (e.g. to obtain the required degree to allow entrance to the Armed Forces officer training scheme), or alternatively because they decide to pursue a career within a different profession (e.g. accountancy).

6 CONCLUSIONS

The Medical Engineering programme at Cardiff University consists of six key threads that have been tailored to deliver a patient-centred engineering degree. The high programme quality is evidenced by the ongoing IMechE accreditation, high applicant numbers, and strong graduate employment.

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