Analysis of Biomedical Engineering Programs in Twelve Universities

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CONTEXT
Biomedical Engineering has been a dynamic, innovative and fast changing discipline allowing for the application of engineering knowledge and skills into medicine and biology. The School of Engineering at Deakin University is planning to devise a modern undergraduate curriculum in Biomedical Engineering to address the needs of the population in Victoria's western district in this time of rapidly changing technology. An important step in formulating the undergraduate curriculum in Biomedical Engineering is the investigation and analysis of existing Biomedical Engineering curricula.

PURPOSE
The aim of this research is to investigate the structure and content of undergraduate programs in Biomedical Engineering across several national and international universities. To ensure that a good range of information is collected, twelve national and international universities from among different university tiers are targeted. The commonality and differences among the Biomedical Engineering programs delivered in the selected universities are identified based on subjects, contact hours, and assessment methods. The outcome of the research will be used to inform the development of a new undergraduate curriculum in Biomedical Engineering at Deakin University.

APPROACH
The investigation is carried out in four stages: program selection, data collection, data analysis and outcome formulation. In a subject-based analysis, a list of subjects is compiled based on the content of the subjects offered by the universities. The subjects required by each university to complete the degree are then compared. In a program-based analysis, the subjects are grouped into twelve overarching program components. The number of subjects in each program component and the average percentage coverage of each program component per university are calculated. In a contact-hour-based analysis, the total number of contact hours for lecture, tutorial and practical is calculated for individual subjects and program components. In an assessment-based analysis, the percentage weighting of four assessment methods is determined for individual subjects and program components.

RESULTS
The following subjects were included in 80% of the programmes investigated: Biomechanics, Human Physiology 1, Materials 1, Mathematics A, Physics and Capstone Project. Management & Professional Skills, Mechanical, Science and Project Based Learning & Industrial Experience were program components featured most in the reviewed universities. The Mathematics component had more lecture hours, whilst the Bioelectronics component had more practical hours. The average contact hours for the Signals and Control component was the highest. Project Based Learning & Industrial Experience and Modelling and Programming had the lowest examination assessment. Signals and Control showed the highest examination assessment. The lab/project assessment of the Mathematics and Biomedical Signals components was small.

CONCLUSIONS
The main outcome of this research is the identification of cohesion in the Biomedical Engineering programs delivered in various countries. For the selection of subjects for a new Biomedical Engineering program, the subjects with higher average percentage coverage are selected first. Then, based on the objectives of the program, the remaining subjects are chosen from among the list of subjects with lower average percentage coverage. In the same manner, the contact hours and assessments are devised for each subject.

KEYWORDS
Biomedical engineering, program analysis, curriculum design.

Introduction

According to recent employment surveys (Engineers Australia, 2015), degree qualified engineers have enjoyed above average employment growth when compared to skilled employment and more than double that of the labour force in general. However, with the transition away from the resources boom, the engineering workforce in Australia is changing and will continue to do so into the future. The increasing commitment by the Australian government to innovation is changing the job market, and stimulating modernisation and workforce development in a number of disciplines. Biomedical Engineering has always been a dynamic, innovative and fast changing area of engineering. This discipline allows for the application of key engineering knowledge and skills into the medical industry, and continue the tradition of great Australian innovation which has spawned inventions like the bionic ear.

To educate for an innovative future, address the needs of an aging population (Australian Institute of Health and Welfare, 2014), and ensure the effectiveness of the engineering courses in the time of rapidly changing technology and processes, the School of Engineering at Deakin University is planning to devise a modern undergraduate curriculum in Biomedical Engineering. An important first step in formulating the curriculum is to investigate and analyse the Biomedical Engineering curricula across several varying-tier national and international universities. Investigations of some engineering curricula in different universities can be found in the literature (Kouzani et al., 2010; Lee, et al., 2008; Memon, 2007; Mouthaan, Brink, & Vos, 2002; Shepstone, 2009).

In this paper, the structure and content of undergraduate programs in Biomedical Engineering offered by twelve national and international universities are investigated. The investigation focuses on the structure and content of the programs, and also the contact hour and assessment of the subjects covered in the programs. The collected data, as well as the analysis results and associated discussions are presented.

Methodology

The analysis of the Biomedical Engineering curricula is carried out in four stages: (i) program selection, (ii) data collection, (iii) data analysis, and (iv) data evaluation and outcome formulation. In the initial stage a number of universities in Australia, Asia, Europe, New Zealand and the USA are identified, which offer undergraduate Biomedical Engineering programs. In the second stage, the data associated with the Biomedical Engineering curricula offered in the selected universities are collected from the official websites of each university, or if unavailable, by contacting the relevant authority in the associated university. In the third stage, the collected data are analysed by formulating the main program components of the Biomedical Engineering programs offered in the selected universities, and then carrying out four investigations including subject, program-component, contact-hour, and assessment based analysis. In the final stage, based on the outcome of the first three stages, further investigation is performed to devise the outcome on the structure of a Biomedical Engineering program.

Universities

To ensure that a good mixture of information is collected and that the data are comprehensive and meaningful, a total of twelve national and international universities from among different tier universities are selected. To identify and select the appropriate universities that offer Biomedical Engineering programs, and that fall into different university tiers, many more universities and their engineering offerings need to be investigated. The investigation is carried out by using the universities respective websites, catalogues available publically, or alternatively through direct contact with relevant authorities in the associated university. The twelve selected universities are from Australia, Asia, Europe, New Zealand

and the U.S.A. Five universities are selected from Australia, one from Singapore two from the U.K., one from New Zealand and three from the U.S.A. For the universities which offered a generalised engineering bachelor's degree with a biomedical specialization or major the subjects required by this specialization were included. In all other cases the required core subjects from the Biomedical Engineering Bachelor were selected for analysis. Table 1 lists the twelve universities selected as well as the degree title, department and duration of each program.

Table 1: Universities selected for analysis of Biomedical Engineering programs

Country	University	Department	Degree	Course	Duration
AUSTRALIA	RMIT	School of Engineering	Bachelor of Engineering	Biomedical Engineering (Honours)	4 Years
	Flinders University	School of Computer Science, Engineering & Mathematics	Bachelor of Engineering	Biomedical Engineering (Honours)	4 Years
	University of Sydney	School of Engineering and Information Technologies	Bachelor of Engineering	Biomedical Engineering (Honours)	4 Years
	Australian National University (ANU)	College of Engineering and Computer Science	Bachelor of Engineering	Biomedical Systems (Honours)	4 Years
	Queensland University of Technology (QUT)	College of Engineering & Computer Science	Bachelor of Engineering	Medical Engineering (Honours)	4 Years
NEW ZEALAND	University of Auckland	Department of Engineering Science	Bachelor of Engineering	Biomedical Engineering (Honours)	4 Years
USA	Johns Hopkins University	Department of Biomedical Engineering	Bachelor of Science	Biomedical Engineering	4 Years
	Cornell	School of Biomedical Engineering	Bachelor of Science	Biomedical Engineering	4 Years
	Georgia Tech	Department of Biomedical Engineering	Bachelor of Science	Biomedical Engineering	4 Years
SINGAPORE	National University of Singapore (NUS)	Department of Biomedical Engineering	Bachelor of Engineering	Biomedical Engineering	4 Years
UK	University College London (UCL)	Department of Medical Physics and Biomedical Engineering	Bachelor of Engineering	Biomedical Engineering	3 Years
	Kings College London	Department of Biomedical Engineering	Bachelor of Engineering	Biomedical Engineering	3 Years

Subject-based Analysis

After the university selection is complete, the structure and content of the undergraduate Biomedical Engineering programs offered by the universities are investigated. The subjects covered in each program and their contents are examined using the information collected from the universities websites, catalogues, etc. All identified subjects are compared among the twelve programs. Only required/core subjects were considered as some universities had an extensive number of electives (50+) which could significantly skew the results. Overall, a list of 70 subjects is constructed based on the subjects found in the twelve programs. After the identification of the subject among each of the twelve universities is complete, a table with 70 rows and 12 columns is produced. For each of the 70 subjects, the universities which require them as core subjects are marked. A number of the subjects appear in many more of the undergraduate Biomedical Engineering programs than others. This information can be used in the selection of subjects for a new Biomedical Engineering program where the subjects which appear more often could be selected first. Then, depending on the aims and objectives of the program, the remaining subjects could be chosen from among the list of subjects with less occurrences. Figure 1 displays a percentage coverage of each subject indicating what percentage of the programs require them as core subjects.

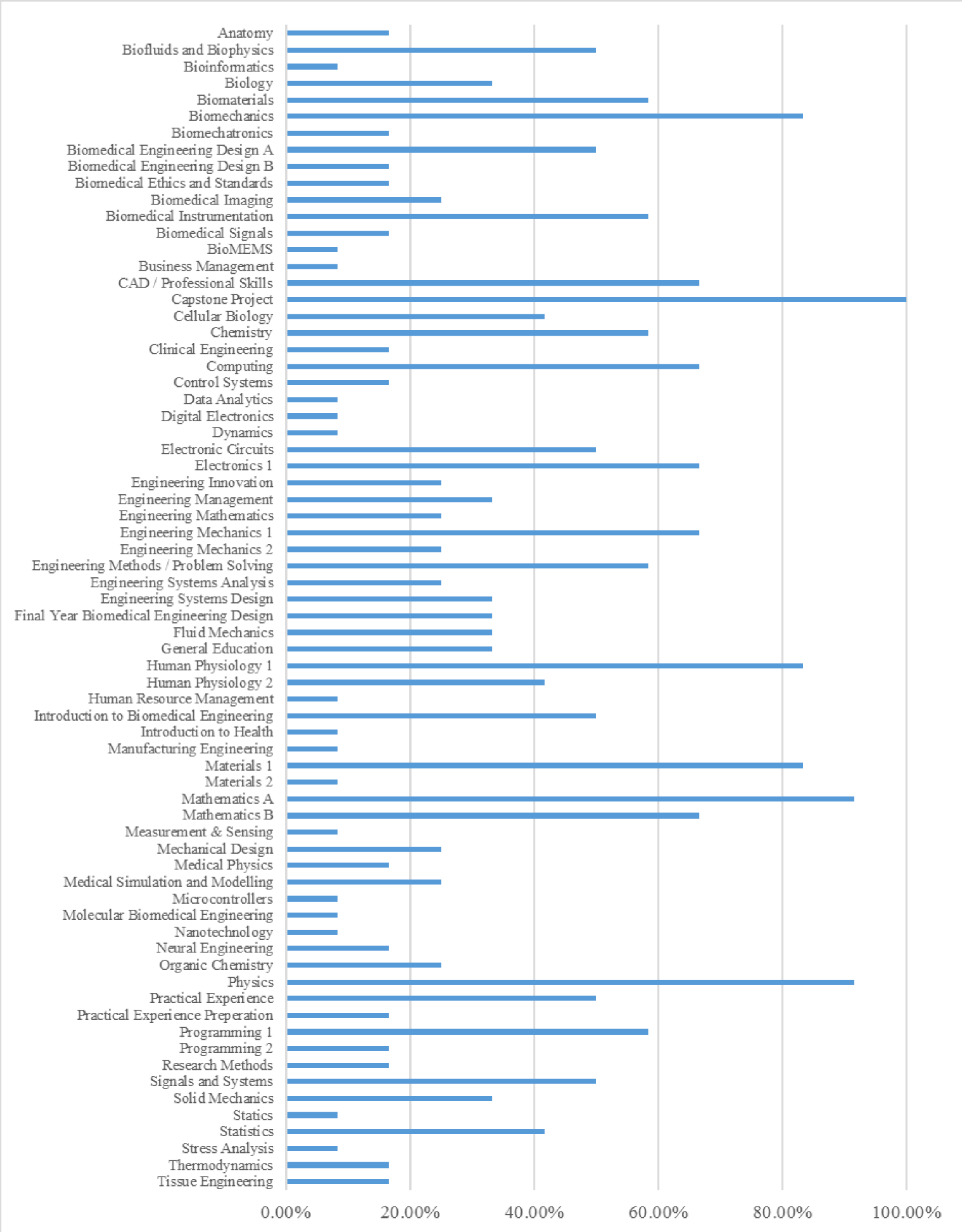

Figure 1: Percentage coverage of each subject

Components of a Biomedical Engineering Program

The 70 subjects identified in the twelve reviewed Biomedical Engineering programs are grouped into twelve component groups. The groups are devised to identify the extent of the Biomedical Engineering programs and the range of different subjects that could be offered in a new Biomedical Engineering program. The grouping exercise is not a straightforward task because of the variation in the program structures as well as subjects across the examined programs. Table 2 outlines the identified components of a Biomedical Engineering undergraduate program and the grouping of the 70 subjects into the program components.

Table 2: Components of a Biomedical Engineering program

1. Science	2. Mathematics	3. Health
Biology Chemistry Physics Organic Chemistry Cellular Biology Molecular Biomedical Engineering Introduction to Biomedical Engineering	Engineering Mathematics Mathematics A Mathematics B Statistics	Introduction to Health Anatomy Human Physiology 1 Human Physiology 2 Medical Physics Clinical Engineering
4. Modelling and Programming	**5. Electronics**	**6. Bioelectronics**
Computing Programming 1 Programming 2 Medical Simulation and Modelling	Digital Electronics Electronic Circuits Electronics 1 Microcontrollers Measurement & Sensing	Biomechatronics Biomedical Instrumentation
7. Signals and Control	**8. Biomedical Signals**	**9. Mechanical**
Control Systems Data Analytics Signals and Systems	Bioinformatics Biomedical Imaging Biomedical Signals Neural Engineering	Engineering Mechanics 1 Engineering Mechanics 2 Solid Mechanics Statics Materials 1 Materials 2 Dynamics Fluid Mechanics Mechanical Design Stress Analysis Manufacturing Engineering Thermodynamics Nanotechnology
10. Biomechanical	**11. Management & Professional Skills**	**12. Project Based Learning and Industrial Experience**
Biofluids and Biophysics Biomaterials Biomechanics BioMEMS Tissue Engineering	Engineering Management Business Management Human Resource Management Engineering Innovation Practical Experience Preparation Research Methods Engineering Methods / Problem Solving Biomedical Ethics and Standards General Education CAD / Professional Skills	Practical Experience Capstone Project Biomedical Engineering Design A Biomedical Engineering Design B Engineering Systems Analysis Engineering Systems Design Final Year Biomedical Engineering Design

Program Component-Based Analysis

To aid in developing a comprehensive view of the components of the components of the twelve undergraduate Biomedical Engineering programs the breakup of each program into the twelve identified components was performed. To identify which program components are the most well represented within the twelve programs the graph in Figure 2 was developed. This figure shows the number of subjects offered by the twelve universities within each of program components and also which universities offer those programs.

Contact Hour-Based Analysis

The twelve Biomedical Engineering programs are studied and the teaching methods for different subjects across the twelve universities are identified. A range of different approaches are identified in teaching of subjects depending on the content of the subject, the year of offer, the program, and the university.

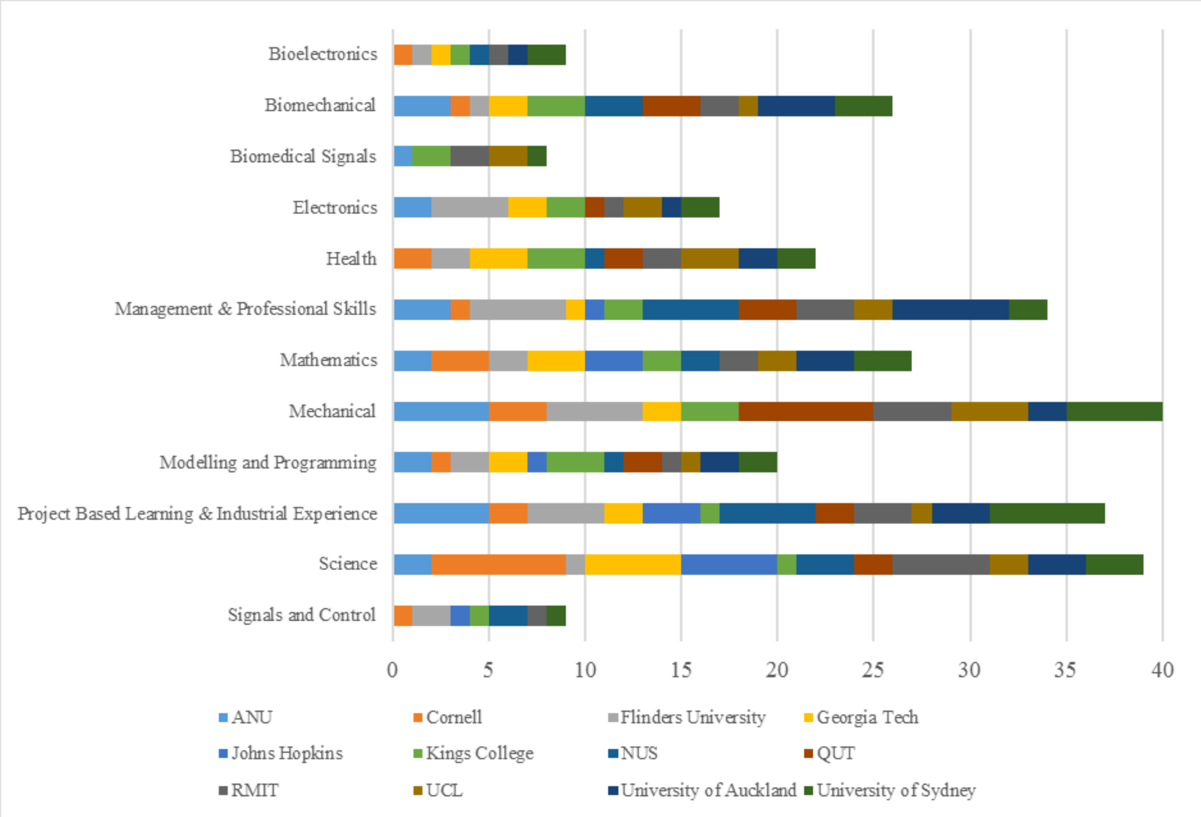

Figure 2: Number of subjects offered in each of the twelve program components

Three common teaching methods are determined: lecture, tutorial, and practical. The lecture provides a context on which the subject is built. The lecture sequence that is presented by a lecturer builds a story about the subject and delivers it to students. The tutorials give students an opportunity to receive individual attention, feedback, advice and suggestions from a tutor. The students get a chance to actively engage with the unit content, assess their own progress, and get to know other students. Practicals give students an opportunity to try out their development skills and assess their own progress. Some subjects are found to include a major project. In this report, the project work is also listed under the practical for simplicity. For each of the seventy subjects a representative subject from one of the twelve universities is selected and the total contact hours for lecture, tutorial, and practical for that subject are calculated. These are then combined into the twelve program components and an average is taken. Figure 3 illustrates the overall average contact hours per program component for a teaching semester among the twelve universities.

Assessment-Based Analysis

Depending on the subject, program structure, and university, the seventy identified subjects are assessed in a number of different ways in the twelve universities. Four common assessment methods are determined as follows: assignment, test/quiz, lab/project, and examination. The assignment requires the student to work outside of the contact hours of the subject to finish an assessment. Students are permitted to use any material to aid in the completion of the assessment. The test/quiz assesses students either in an unsupervised or a supervised manner while they complete a small set of questions. The lab/project assesses students' practical skills where they carry out hands-on experiments or a major project. The exam assesses students in a supervised manner while they complete a comprehensive set of questions about various aspects of the subject they have learnt. In a similar manner to that employed in the contact hour-based analysis, for each of the seventy subjects a representative subject from one of the twelve universities is selected and the assessment makeup (assignment, test/quiz, lab/project, and examination) for that subject is calculated.

These are then combined into the twelve program components and an average is taken. Figure 4 displays the average percentage of the four assessment methods for each of the twelve program components among the twelve universities.

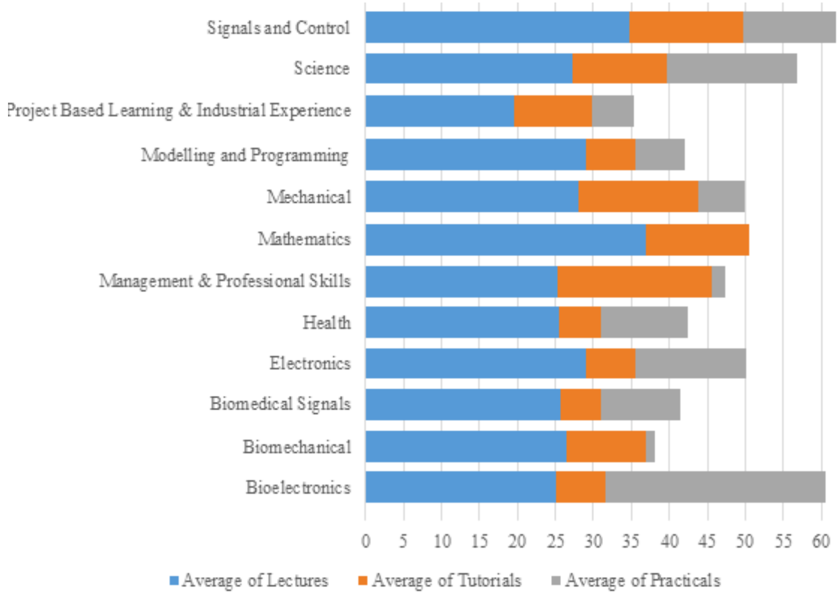

Figure 3: Average contact hours per program component

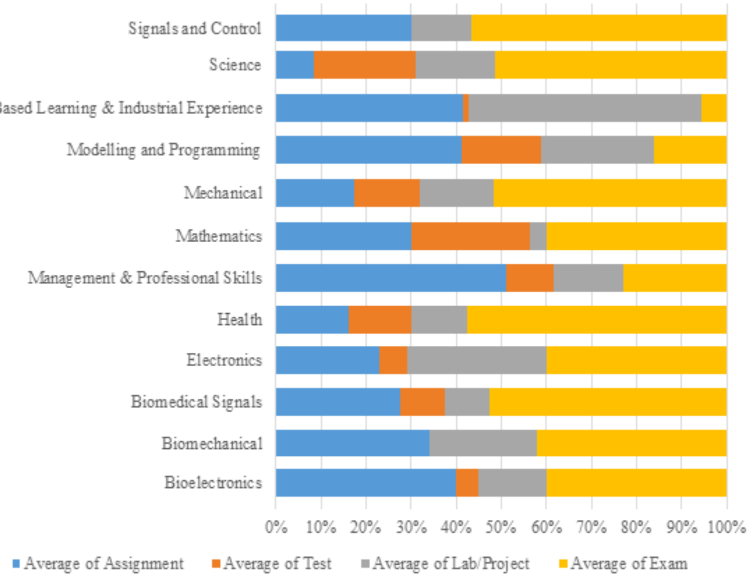

Figure 4: Average percentage of the 4 assessment methods for each of the 12 program components

Discussions

The following subjects were included in 80% of the programmes investigated: Biomechanics, Human Physiology 1, Materials 1, Mathematics A, Physics and a Capstone project. Management & Professional Skills, Mechanical, Science and Project Based Learning & Industrial Experience components were featured most in the Biomedical Engineering program of the reviewed universities. The Mathematics component had more lecture than practical hours, whilst the Bioelectronics component had more practical than lecture hours. Also, the average contact hours for the Signals and Control component was the largest, whilst the Project Based Learning & Industrial Experience component had the least average contact hours.

Project Based Learning & Industrial Experience and Modelling and Programming had the least part of their assessment dedicated to examinations. The lab/project assessment of the Mathematics and Biomedical Signals components were very small, however, the rest of their assessment was mixed between Assignments, Tests and Examinations. The assignment assessment varied among the twelve components, where Signals and Control showed the largest examination assessment among the others.

The main outcome of this research is the identification of cohesion in the Biomedical Engineering programs delivered in various countries. This information would facilitate the development of a new curriculum in Biomedical Engineering. For the selection of subjects for a new Biomedical Engineering program, the subjects with higher average percentage coverage could be selected first. Then depending on the objectives of the new program, the remaining subjects could be chosen from among the list of subjects with lower average percentage coverage. In the same manner, the contact hours and assessments can be devised for each subject using the information presented in the paper.

Conclusion

The School of Engineering at Deakin University is considering the introduction of an undergraduate curriculum in Biomedical Engineering. To formulate an appropriate course map including a list of subjects for the proposed program, and also to devise right contact-hours and assessment methods for individual subjects in the program, the cohesion and commonality in terms of structure, subjects, contact-hours, and assessment methods among the Biomedical Engineering programs offered in different universities needed to be investigated. The data associated with the Biomedical Engineering curricula offered in the selected universities were collected. The data were then analysed by carrying out four investigations including subject, program, contact hour, and assessment based analysis. Considering the analysis results presented in the form of several figures within the report, the main outcome of this research is the determination and presentation of uniformity in the Biomedical Engineering programs delivered in various countries. This information facilitates the development of the new curriculum in Biomedical Engineering. For the selection of subjects for the new Biomedical Engineering program, the subjects with higher average percentage coverage are selected. Then, based on the objectives of the new program, the remaining subjects are chosen from among the list of subjects with lower average percentage coverage, or those that were not even found in the twelve programs. Moreover, the contact hours and assessment methods are devised for each subject using the information presented in the report.

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