Sax Institute

Evidence Check

Biomedical engineering: a critical workforce in healthcare delivery

An Evidence Check rapid review brokered by the Sax Institute for the NSW Ministry of Health. January 2020.

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Background and approach

The NSW Ministry of Health (Ministry of Health) identified the biomedical engineering workforce as a *"small but critical workforce"* of 37 Full Time Equivalent (FTE) biomedical engineers working in NSW Health. This small but critical workforce is defined as a *"workforce which contributes critical and essential elements of a comprehensive health service and is currently experiencing threats to meet system needs now and into the future."*

This Evidence Check report results from a study undertaken by a team in the Centre for Workforce Futures at Macquarie University that addressed two overarching questions:

- What is the current state of the biomedical engineering workforce in NSW Health?
- What are the challenges in maintaining this workforce?

This Report draws on:

(i) the 'Biomedical Engineering Workforce – Workforce Scoping Report – small but critical workforces' prepared by the Ministry of Health
(ii) a desktop review submitted to the Sax Institute and the Ministry of Health on 8 July 2019 following a comprehensive literature search, using a search strategy and key terms agreed to by the Ministry of Health
(iii) 12 interviews conducted with Key Informants (see Appendix A for pseudonyms and sector of employment for interviewees).

Approach

The desktop review was conducted between 21 June and 5 July 2019 to identify relevant peer-reviewed and grey literature published from 2013 onwards, from Australia and other relevant countries, pertinent to the areas of research and questions specified in Proposal for Review Team, which included:

1. the current definitions and state of the biomedical engineering (BME) workforce in NSW Health (including demographic profile, required competencies and capabilities for BMEs in NSW Health, duties and functions, relationships with biomedical technicians and other clinical staff)
2. training pathways and qualifications, training programs in Australia and career pathways
3. recruitment and retention issues
4. future challenges (including technological change and other drivers of change in healthcare delivery)
5. the current state of BME employment in other Australian States and countries.

The interviews were conducted between 2 August and 10 October 2019 using the interview schedule developed by the research team in collaboration with representatives from the Ministry of Health and the Sax Institute and approved by the Macquarie University Ethics Committee (Ethics Reference No: 5201956969662 for Project Title: Biomedical Engineering Workforce Project ID: 5696). In accordance with Ethics approval granted for the project, all twelve interviewees were assigned a pseudonym to ensure confidentiality and privacy.

The interviewees included Biomedical Engineers (BMEs) and Directors of BMEs from the public and private health sector, including hospitals and Local Health Districts (LHD), two Australian higher education institutions and representatives from Engineers Australia. The interviews were transcribed and coded using the keywords and selection criteria encompassed by the topic areas and questions specified in Proposal for Review Team pertinent to the overarching and subsidiary research questions.

Executive summary

Key findings and recommendations overview

Key finding 1. Data and knowledge – critical gaps in data, knowledge and literature

There is an urgent need to overcome the lack of adequate data and knowledge on the biomedical engineering workforce employed in health services generally and in NSW Health specifically.

The research conducted for the desktop review found that the extant international and Australian literature on the Biomedical Engineering (BME) workforce employed in the health services sector is limited. Australian and State Government future workforce reports and strategies for health care predominantly focus on primary health services by doctors, allied health professionals and nurses with limited attention given to biomedical engineering.

In addition, a preliminary review of Department of Jobs and Small Business. 2017 Employment Projections found that 'Biomedical Engineers' was not included in the Engineering Profession category and that 'Biomedical Engineering Technician' was not included in the Engineering Trades category in the Australia wide data. The same applies to the NSW data 'Labour Market Research – Engineering Professions NSW April 2018' and 'Labour Market Research Health Professions NSW June 2018', and the category Health Professions. The ABS data is of limited value as BME is not a discrete occupation in the 2016 Census and can only be searched as a qualification category/field of study.

The biotechnology sector has received more attention. Reports produced by companies, such as Deloitte (Snyder 2015) and Ausbiotec-Grant Thornton (2019), and also the McKell Institute (Hine and Marieke 2016) focus on the manufacturing supply chain, consider the importance of emerging technologies in quality control and assurance, the growing importance of AI for medical device companies and the role that it can play in training people to use their products and need for government investment and regulation.

The interview data collected for this project currently provides the best insights into the current state of and future challenges facing the BME workforce in NSW Health. However, while the data is rich, the findings are constrained by the small size of the sample.

Recommendations:

- **Undertake a comprehensive survey of BME workforce in NSW Health** following the approach adopted by the Australasian College of Physical Scientists and Engineers in surveys undertaken in 2009 and 2012–13 (Round 2013) to obtain the necessary data on the current state of the BME workforce in the NSW health services sector

- **Undertake case study research in NSW Health across Local Health Districts and hospitals** following the approach adopted in the Institution of Mechanical Engineers (2014), Report: Biomedical Engineering: Advancing UK Healthcare to identify best practice approaches to defining and managing biomedical engineering and factors likely to affect the future of the BME workforce in health.

Key finding 2. Need to clarify BME role definition

Definitional confusion surrounds the BME workforce employed in health services generally and in NSW Health specifically, compounded by (i) the fragmented nature of the discipline; (ii) use of the term Clinical Engineering (CE) as a sub-speciality of biomedical engineering in health services; and (iii) the absence of a registration/certification system for BMEs/CEs employed in health services in NSW.

Lack of clarity surrounding the BME workforce relates to the existence of multiple definitions adopted by different bodies: Australian and New Zealand Standard Classification of Occupations [ANZSCO], Engineers Australia [AE], the American College of Clinical Engineering [ACCE]; the National Health Service [NHS] in the United Kingdom and the World Health Organization [WHO].

Biomedical engineering is depicted as 'a fragmented discipline', with BMEs inconsistently 'divided and absorbed' across a range of departments. Accordingly, there is an urgent need for biomedical engineers to be classified "*as a distinct professional group within engineering professionals"* to *"validate the essential role that biomedical engineers should play in health-care systems*" (WHO 2017) and for biomedical engineers to be better integrated into healthcare systems and organisations (Finlay et al. 2014).

In order to enable more effective classification of BMEs working in health-care systems, some organisations have adopted the term 'Clinical Engineer' as a sub-specialty of Biomedical Engineering. Several Key Informants who participated in this study suggested that 'Clinical Engineer' would be more appropriate term for those BMEs who apply engineering principles within healthcare environments and in hospitals, working with medical equipment, providing support for medical equipment, managing equipment and resolving complex issues and problems around medical equipment. There are several definitions of Clinical Engineer (CE), as follows:

(i) 'Clinical Engineering' is "*a specialty within biomedical engineering responsible primarily for applying and implementing medical technology to optimise healthcare delivery*" (Engineers Australia 2019)

(ii) A clinical engineer "*is a professional who supports and advances patient care by applying engineering and managerial skills to healthcare technology*" (The American College of Clinical Engineering [ACCE] 1992, Brochure 2018)

(iii) 'Clinical Engineers design, develop and maintain equipment for diagnosing illness and treating patients' (UK National Career Service https://nationalcareers.service.gov.uk/job-profiles/clinical-engineer)

(iv) *"Clinical engineers use their specialised engineering knowledge in implementing healthcare technologies and strategies in hospitals and other health-care settings. The selection, installation and ongoing support of appropriate technologies and associated equipment used by healthcare professionals are critical to the delivery of safe and effective health-care*" (WHO 2017).

The lack of definitional clarity is compounded by the absence of a registration/certification system for BMEs/CEs in NSW. Registration for health services with associated standardised minimal qualifications would help to define the scope of the role in health and enable maintenance of professional and health standards leading to better recognition of the value of BMEs/CE in the health services sector.

In this regard, policy options could include the adaptation for NSW of the general engineering registration system operating in Queensland. This could include consideration of (i) the formation of a regulatory board in the form of an independent statutory body with responsibility for regulating the BME profession across NSW Health and for maintaining a fair and consistent set of standards of engineering conduct for healthcare purposes, and (ii) the introduction of assessment processes for BMEs/CEs employed in NSW Health in association with Engineers Australia (see: https://www.bpeq.qld.gov.au/; https://www.bpeq.qld.gov.au/about-our-company/our-role/). NSW Health may also consider the joint Healthcare Technology Certification Commission approach adopted by Canada and the US.

Recommendations:

- **NSW Ministry of Health address the definitional confusion surrounding the BME workforce** by hosting a focus group discussion with representatives of the BME workforce to decide on best definition and consider the potential for workforce policy and/or registration. **Such a forum could explore the value of adopting the term Clinical Engineer for BMEs working in healthcare settings** and select from one of the above definitions as a basis for more effective classification, identification, integration and deployment of BMEs in NSW Health
- **NSW Ministry of Health develop a BME/CE workforce policy**, including a certification strategy and a system and structures for managing the registration of BMEs/CEs employed in hospitals and related public health services in NSW.

Key Finding 3. Demographic dimensions of the BME Workforce

Demographic data on the BME/CE workforce in NSW Health is extremely poor. Out-of-date data indicates an ageing workforce, low numbers of junior BMEs and a growth in the number of women in the broader BME graduate workforce pool.

According to interview data the figure of 37 FTE BMEs in NSW Health significantly underestimates the true numbers of BMEs employed in NSW Health.

In addition, while the Australian Bureau of Statistics (ABS) 2016 Census data on the discipline of BME generally suggests that younger age groups dominate the profession, that data cannot be used to identify the demographics of the BMEs in public health (or in the broader population).

BME survey data collected by the Australasian College of Physical Scientists and Engineers in Medicine in 2009 and 2012, which applied only 'to the workforce in the public sector' (Round 2013, p147) found that the size of the BME "*workforce hardly changed at all between 2009 and 2012; in fact, it decreased by 6%*." A comparison between the 2009 and 2012 survey outcomes suggested "*a trend towards an aging workforce*" with increases in the "*number of the more senior engineers*" and decreases in "*the number of the most junior engineers"* (Round 2013, p155). This data is now out-of-date, but the trends are unlikely to have changed. This is of concern for NSW and Australia given that at the time in the US biomedical engineering was described as a "*fast-growing workforce"* (Round 2013, p155).

BME is ahead of other areas of engineering in the recruitment of women. Documentary and interview sources conclude that the unique crossover between Science, Technology, Engineering and Math (STEM) and the direct interaction with people and health inherent in BME/CE work makes this field an attractive career choice for women (Strimel et al. 2018).

Recommendation:

- **Undertake a comprehensive survey of the BME workforce in NSW Health** following the approach adopted by the Australasian College of Physical Scientists and Engineers in surveys undertaken in 2009 and 2012–13 (Round 2013) to obtain the necessary demographic data on the current state of the BME workforce in the NSW Health sector to determine the impact of age and gender factors on the current workforce and as a basis for the development of a strategic recruitment and retention strategy in NSW Health.

Key Finding 4. Human Resource Implications of demographic factors

Recruitment, retention and career pathways pose significant challenges for the BME/CE workforce in NSW Health as a result of the lack of a strategic approach to recruitment of BMEs/CEs for NSW Health generally and hospitals specifically, competition from the private sector, and lack of career pathways.

The demographic factors outlined above highlight the urgent need to ensure future staffing needs are met as current staff retire. The most significant local recruitment and retention challenges identified include:

(i) an imbalance between supply and demand in health services. BME has witnessed a rise in popularity among engineering graduates, and especially among female engineers (Hine 2016) and larger numbers are graduating. However, employment opportunities in NSW public health are limited (Dokos 2015)

(ii) public health service recruitment of highest quality graduates is constrained by local and global competition from the growing private biotechnology sector (10% between 2007 and 2016) and the attraction of private sector design and innovation work and research work in universities

(iii) recruitment is hampered by the absence of a **strategic approach** to hospital-based internships for BME degree students. With minimal exceptions, current BME internships preference private sector organisations rather than public health sector organisations and hospitals. Work-experience/internship programs in hospitals are currently provided on an ad hoc and localised basis

(iv) starting salaries for BMEs in health compare favourably to private sector rates but are not competitive for senior levels

(v) lack of adequate career pathways and the routine nature of the work in hospital settings reduce capacity to retain talent.

Recommendations:

- **Develop a comprehensive and integrated recruitment strategy** for BMEs in NSW Health focused on the patient-care sub-speciality of clinical engineering to attract more graduates and particularly women to this field in NSW Health, including a generalised internship program across all Local Health Districts (LHDS)/Specialty Networks (SNs)
- **Develop a recruitment communications strategy** to increase visibility and awareness of BME/CE roles and careers across NSW Health, including representation at university careers fairs and an improved recruitment page on the NSW Health website
- **Develop structures and mechanisms that can facilitate opportunities for career progression, career development and upskilling**, including an exclusive graduate program for BMEs/CEs in the public health system as a valuable avenue for retention.

Key Finding 5. Impact of technological changes on BME/CE Workforce:

Technological changes and the introduction of more integrated systems for the provision of biomedical technology services in hospitals is decreasing the traditional functional demarcation between BMEs and Biomedical Engineering Technicians (BMETs). The concurrent medical device integration with IT systems is decreasing demarcations between BMEs and IT professionals in health services.

These technological and functional changes, combined with growing demands for patient-centred care require greater communication between BMEs/CEs, clinicians, allied health professionals and patients, giving rise to the need for a range of new ‘soft skills’ for BMEs/CEs in health care settings.

Traditionally the BMET function centred on medical equipment repair, testing and preventative maintenance services and BME responsibilities included the management oversight of medical equipment systems, financial or budgetary management, service contract and procurement system management, supervision of in-house maintenance staff, participation in planning for and assessment of new technology, assuring regulatory compliance of medical technology management, investigation of incidents, and active participation in training.

Such traditional functional demarcations between the university-trained engineers and the TAFE trained technicians are rapidly diminishing partly as a result of technological change and partly as a result of the increasing employment of graduates at BMET levels in public health services.

In addition, the shift in the clinical environment from standalone medical devices to integrated clinical systems is blurring the lines between medical, communications, and information systems and in turn, the functions of BME/CE staff and information technology staff (McAlpine and Vankampen 2011, ACCE Brochure 2018).

Medical device integration and technological and systems developments in data collection, processing and AI provide immense opportunities for BMEs/CEs in health services, while also creating the need for a range of additional skills and competencies for the BME workforce in clinical settings, including in IT for health systems, risk management, procurement, trouble shooting and problem solving and 'soft skills' such as teamwork, communication and leadership skills for clinical health.

BMES/CEs and BMETs need up-skilling, mentoring and competency development opportunities focused specifically on networked health systems and health services, as an addition to technical training provided as part of university and vocational training.

The UK Scientist Training Program (STP) which prepares new graduates with valuable knowledge in how to navigate and work in the NHS can provide guidance. A particularly useful comprehensive approach is provided by the Queensland Government's Clinical Skills Development Service, which encompasses (i) online, face-to-face and blended learning solutions for improved clinical skills and clinical team performance (https://csds.qld.edu.au/ and (ii) an Innovation Hub (https://csds.qld.edu.au/innovation-hub/).

The creation of an Innovation Hub in NSW Health would dovetail with the shift from specialised silos of medical and engineering knowledge to more centralised and accessible knowledge centres, identified in the US, which "*allow clinicians to provide sophisticated care without necessarily having specialised training*" (Snyder 2015).

Recommendations:

- Develop a strategic and comprehensive NSW Health focused training program specifically for the BME/CE & BMET workforce in NSW LHDs/SNs to enable up-skilling and capability building to meet the new needs of integrated healthcare services and systems in association with the Health Education and Training Institute
- Consider development of an Innovation Hub for BME/CE in NSW Health, integrated with HealthShare and the Agency for Clinical Innovation, to enable cross-disciplinary collaboration among BMEs/CEs and BMETs, IT staff, medical, allied health, nursing and other clinical staff to collaborate on the generation of new ideas, devices, and methods that can improve the delivery of patient services, patient safety, and to address complex problems in healthcare in NSW.

Key Finding 6. Provision of BME/CE Services in NSW and deployment of BME/CE & BMET Workforce:

A tension exists between the current localised approach to BME and BMET workforce employment and deployment in diverse clinical contexts around NSW and the expansion of integrated health structures, services and systems.

The highly localised employment of BMEs and BMETs provides a knowledge base and capacity for rapid response to biotechnical issues and needs in diverse clinical settings. However, lack of centralised BME and BMET workforce management structures and employment/deployment processes and mechanisms limits the ability to tap into the BME/BMET at a state-wide level.

Potential exists for the BME workforce to add greater value to NSW Health through a hub and spoke model that combines centralisation with local staffing and services in LHD/SNs.

A potential model is provided by the Queensland Government's approach to the deployment of the BME/CE workforce across the state through the registered State Government Entity QLD 'Biomedical Technology Services' (registered as a 'State Govt Entity'), which provides "*a comprehensive range of health technology management services and partnering*," that includes onsite service locations at most major public hospitals in Queensland.

A bespoke model could enable better utilisation of the BME workforce.

Some degree of centralisation could more effectively support:

- strategic services and planning, career pathways and development and training
- the convergence of devices and IT, and alignment and integration of critical health/patient services, business processes, data models and activities between IT and biomedical systems
- ensure health data security
- increase BME/CE visibility throughout NSW Health
- improve BME/CE and BMET career pathways and training
- enable strategic redesign of BME/CE & BMET roles and functions to meet evolving needs
- facilitate more effective integration and engagement of BMEs/CEs on state-wide health services structures and projects (including contributions to healthshare and ehealth and networked systems working alongside ICT specialists, design and development of hospital layouts and research and development on and management of new devices/ clinical applications/ apps to aid in health service delivery).

Associated local services could ensure the timely availability of localised expertise and biomedical technology maintenance and service delivery.

Recommendation:

NSW Health consider the introduction of a hub and spoke model for the organisation and deployment of the BME/CE and BMET workforce in the provision of biomedical/ clinical engineering health services in NSW to integrate biomedical engineering more effectively with existing state-wide or specialist health services:

- HealthShare NSW
- Health Infrastructure
- eHealth NSW
- Local Health Districts/ Speciality Networks
- Pillar Organisations: The Agency for Clinical Innovation,The Bureau of Health Information, The Clinical Excellence Commission, The Health Education and Training Institute.

Analysis of current biomedical engineering workforce in NSW Health

Defining the workforce

The Australian and New Zealand Standard Classification of Occupations (ANZCO) defines Biomedical Engineering as:

> *"ANZCO Code: 233913 (BIOMEDICAL ENGINEER): Applies knowledge and methodology of physics, engineering, mathematics, computing, physical chemistry and materials science to problems in biology and the treatment and prevention of human disease. Registration or licensing may be required" (ABS 2013).*

For Engineers' Australia, the country's peak engineering body:

> *"Biomedical Engineering combines a knowledge and practice of electronic, electrical, mechanical, chemical and materials engineering, with the life sciences of medicine, biology and molecular biology" (Engineers Australia 2019a).*

However, both documentary sources and key informants highlighted concerns relating to definitions of this discipline, field and occupation.

In 2014, a Report by the UK based Institute of Mechanical Engineers (IMECHE) entitled, 'Biomedical Engineering: Advancing UK healthcare' noted that:

> *"Currently biomedical engineering is a fragmented discipline: often it is divided and absorbed into other departments, but even this is inconsistent. To obtain the full benefits of cross-disciplinary working, the skills of biomedical engineers need to be understood as a distinct discipline, and integrated into the healthcare interests of academia, industry, NHS and Government."*

Similar concerns were raised in the World Health Organization (WHO) 2017 Report 'Human Resources for Medical Devices, the Role of Biomedical Engineers':

> *"There is an immediate priority to upgrade the professional standing of biomedical engineers worldwide. The classification as a distinct professional group within engineering professionals, will help validate the essential role that biomedical engineers should play in health-care systems, and support the various institutional initiatives (policy, training, certification, staffing, budgets, operational infrastructure, etc.) that will be needed to establish and maintain high global standards for health-care services" (WHO 2017, p146).*

Accordingly, the WHO recommended the reclassification of BMEs and BMTs in order to address *"the increasingly complex nature of advances in biomedical devices and health delivery platforms."*

Although interview participants generally agreed with the ANZCO definition of BME, they also raised concerns about gaps and about its applicability to health generally and NSW Health specifically. For Frankie, important gaps included maintenance of medical technology and leadership skills, people skills and social skills, which are becoming more significant requirements for BMEs in hospital settings.

Several other informants suggested that 'clinical engineer', as a sub-specialty of Biomedical Engineering, would be more appropriate term for BMEs who apply engineering principles within the healthcare environment and in hospitals, and who work with medical equipment, providing support for medical equipment, managing equipment and resolving complex issues and problems around medical equipment

In this regard, several interviewees suggested the adoption of the Engineers Australia definition or the American College of Clinical Engineering definition for clinical engineering, which they thought would be more closely aligned with the role of BMEs in NSW Health.

In fact, there are a number of definitions of clinical engineer, as follows:

Engineers Australia describes 'Clinical Engineering' as "*a specialty within biomedical engineering responsible primarily for applying and implementing medical technology to optimise healthcare deliver"* (Engineers Australia 2019b).

The American College of Clinical Engineering (ACCE) defines a clinical engineer *"is a professional who supports and advances patient care by applying engineering and managerial skills to healthcare technology"* (AACE 2018).

The United Kingdom (UK) National Career Service (NHS) states that "*Clinical Engineers design, develop and maintain equipment for diagnosing illness and treating patients.*" (https://nationalcareers.service.gov.uk/job-profiles/clinical-engineer).

The World Health Organization (WHO) states that "*Clinical engineers use their specialized engineering knowledge in implementing healthcare technologies and strategies in hospitals and other health-care settings. The selection, installation and ongoing support of appropriate technologies and associated equipment used by healthcare professionals are critical to the delivery of safe and effective health-care*" (WHO 2017).

Demographic profile of Biomedical Engineering

According to the 2016 Census, 1,855 individuals identified themselves as employed in Biomedical Engineering across Australia. Of these, 200 identified as managers, 808 as professionals and 149 technicians and trades workers. The remaining 695 were either inadequately identified, filled administrative support roles or selected Not Applicable (ABS 2018a). These figures include individuals working in the private sector doing a myriad of jobs. The ANZSCO code 2399 is the level to which data for BMEs is provided to the public. BME is code 239913, one of 7 occupations—including Aeronautical, Agricultural and Environmental Engineering among others—under the 2399 code. A deeper analysis undertaken, using custom access to ABS data was able to further drill down to those who identified as BMEs, however the categories for where they work did not include 'public sector' or 'hospital'. The earlier BME surveys conducted by the Australasian College of Physical Scientists and Engineers in Medicine, particularly in 2009 and 2012, provided a valuable approach to obtaining more specific data on the BME workforce in the public sector based directly on information from biomedical engineers in established positions (Round 2013, p147). Of note, however, is the age distribution of this workforce (see Figure 1), which shows the relatively recent popularity in the field and the heavy weighting towards the younger age groups across the board, which contrasts with the findings presented in the 2009 and 2012 surveys reported by Round which noted that "*there seems to be a trend towards an aging workforce*" with increases in the number of more senior engineers and decreases in "*the number of the most junior engineers*" (Round 2013, p155). Given the growing numbers of BME graduates, it appears that supply is not as significant an issue as demand.

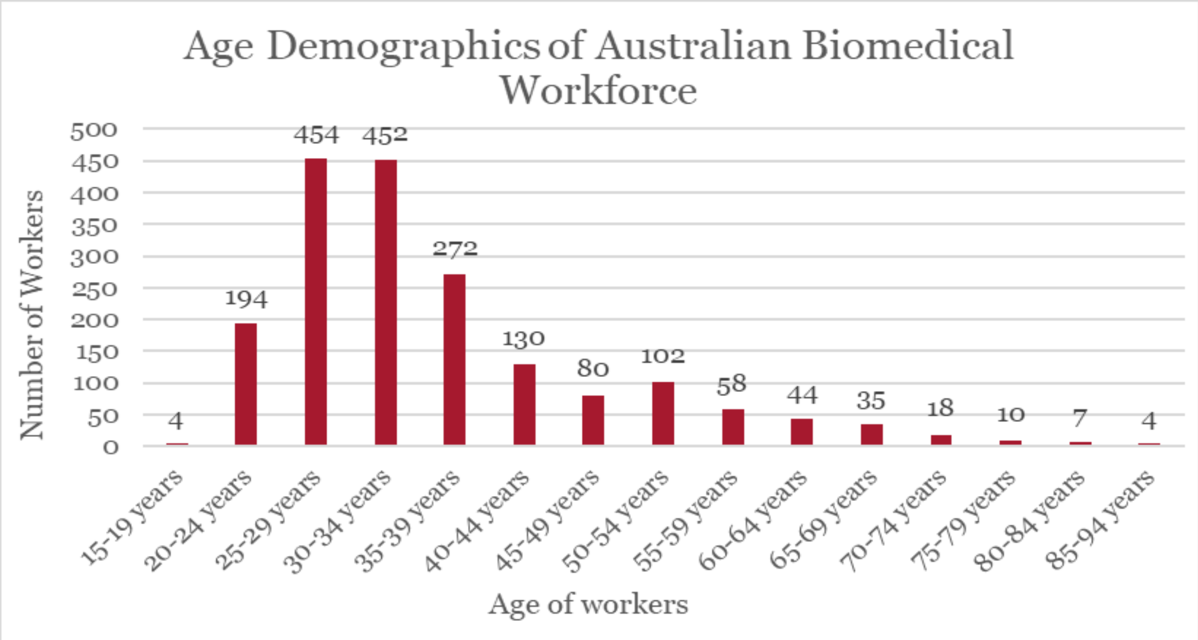


Figure 1—Age Distribution of All Australians Identified as Working in Biomedical Engineering, 2016 Census (ABS 2018a).

According to the Biomedical Engineering Workforce Scoping Review, as of June 2018 there was an equivalent of 37.62 Full Time Employees (FTE) filling the role of 'Biomedical Engineer' within NSW Health (Health 2019).

The consensus of the 12 interview participants is that the 37 FTE recorded for BMEs in NSW Health is an underestimation. None of the interviewees considered that figure was accurate, and a few suggested the number is likely to be in the ballpark of 200 to 300. When they speculated as to how the 37FTE figure was arrived at, some interviewees theorised that it could be because only those with BME degrees had been included. Hence, Morgan found the low number surprising and thought that it could be that only those in the asset management aspect of BME work had been considered. He stressed that:

Morgan: *"biomedical engineers do an awful lot more. So, it's very difficult to put a number on it. … whilst there might only be 37 biomedical engineers, as in qualified with a Bachelor of Engineering, there is also an awful lot more, probably a couple of hundred across the state of biomedical technicians. Which often do much, can do much of the work of an engineer but they don't have the engineering training to do everything."*

Some of the interviewees from the health sector also suggested that this figure possibly only included those biomedical technicians who are covered by the Biomedical Engineering Award, which does not cover the majority of those who work in biomedical engineering departments, but who are potentially classified as clinical engineers (estimated at a couple of hundred), as well as 16 or 17 Directors of Biomedical Engineering in the various Local Health Districts.

One interviewee estimated that the people working in biomedical engineering in NSW Health was probably in the vicinity of 210 or 220. Another pointed out that the classification by HR of the specific job and lack of standardisation is key to this issue.

Frankie: *"it just surprised me when I saw the numbers on how many biomedical engineers we have in New South Wales, so I was expecting to see a much larger number.*

My experience is when I walk into a biomedical engineering department there's anywhere between 8 and 15 what we would class as 'biomeds' in a hospital, and just by means of extrapolation I expect there are hundreds of biomedical engineers across New South Wales Health [….] Digging a bit deeper and understanding the way that the different job types are classified, I think that's where a lot of the grey area comes in and also I'm not sure we've done a good job of defining what are the roles and responsibilities of the different levels."

This raised questions about what precisely those classified as technicians are responsible for. In addition, the existence of numerous managerial titles, such as 'biomed manager', 'chief biomedical engineer', 'director or biomedical engineer, clinical technology', highlights the lack of standardisation of the workforce and the titles that that should be assigned.

Another group of BMEs missing from the existing definition includes those who work in hospitals on research projects funded by research grants. Hence, Charlie commented that such BMEs would not be identified in the statistics because: "*In many cases they're on research funding, or they're employed by the clinical unit … and they would often be described as a research officer, or a hospital scientist."*

Gender Analysis

While engineering graduates are globally dominated by men, the growing numbers of women graduates indicates a positive trend towards a more balanced gender distribution specifically for BME graduates.

The United States (US) has the most in-depth data on Women in Engineering available, including data down to exactly which degrees are being studied. In the US in 2017, women were awarded 21.3% of all Engineering Bachelor degrees (Figure 1a), while 44.0% of BME degree recipients were women, second only to Environmental Engineering (50.0%) in terms of highest proportion of female graduates (Figure 2). This stands in stark contrast to the more traditional fields of mechanical and electrical engineering, where women were awarded just 14.8% and 13.7% of degrees, respectively (Yoder 2017).

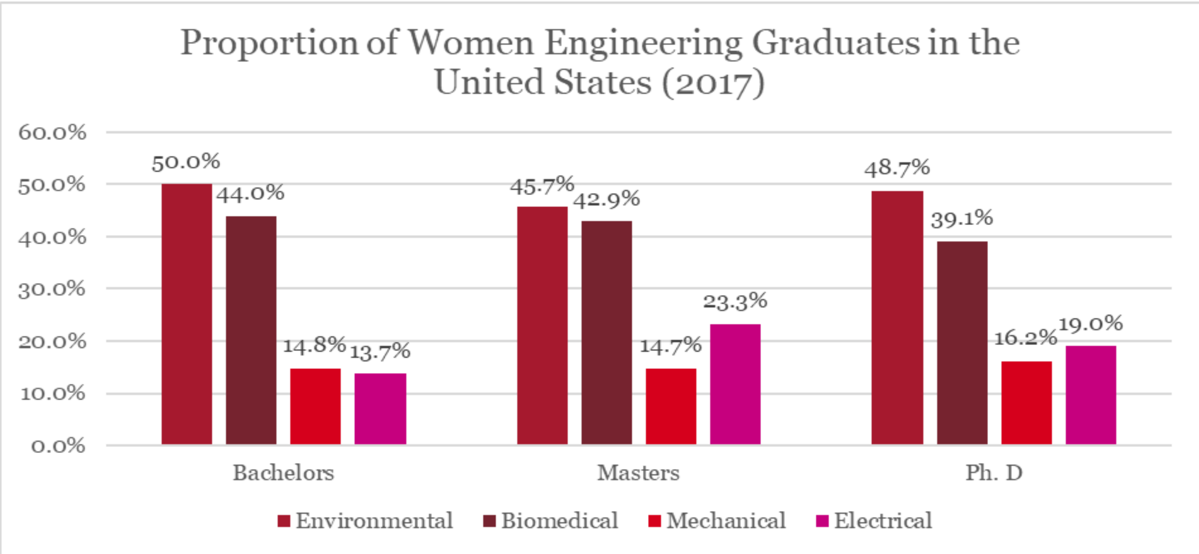


Figure 2—The percent of degrees in environmental and biomedical engineering versus mechanical and electrical engineering, received by women in the US, data from (Yoder 2017).

This trend toward more female participation in BME continues for higher degrees (Figure 1b), such as Masters and Doctorate degree levels, according to the American Society for Engineering Education, a trend that is common across all engineering disciples in America (Figure 1a).

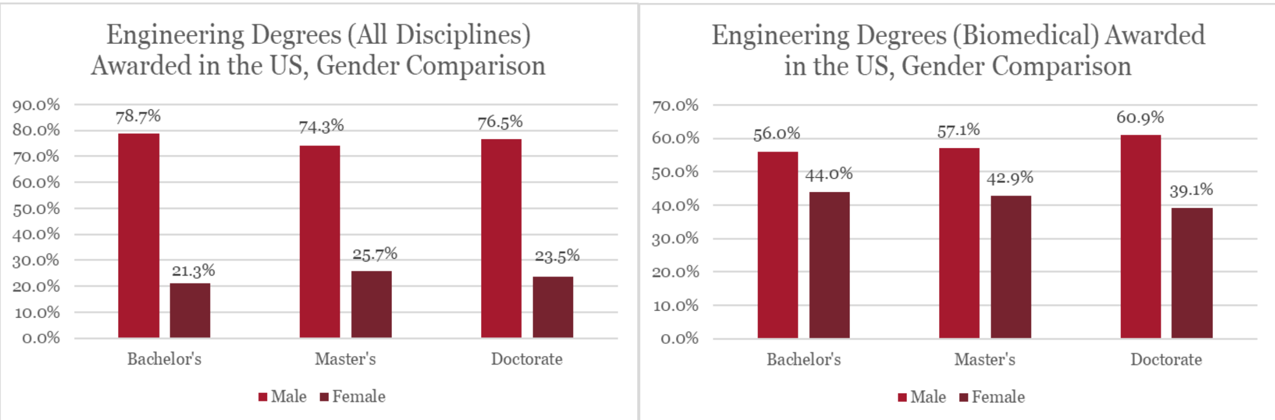


Figure 1—Proportion of graduates by gender, a) across all engineering disciplines in the US in 2017, b) Biomedical only (Yoder 2017).

According to the Australian Government's Workforce Gender Equality Agency (WGEA), across all disciplines and course levels, women made up 59.5% of all graduates while men account for 40.5% of individuals completing undergraduate and post graduate courses. Engineering is one of the few areas of study, along with Architecture & Building and Information Technology, that are male dominated. Engineering and related technologies have a gender split of 16.1% female to 83.9% male graduates (Workplace Gender Equality Agency 2019).

Within Australia, across the broad range of Engineering degrees on offer, it is not clear exactly what the gender split is within the field of Biomedical Engineering. All reports available quote the 2016 Census, where Biomedical Engineering is grouped in with: Environmental Engineering, Fire Technology, Rail Operations, Cleaning and 'Engineering and Related Technologies, n.e.c.' under the Australian Standard Classification of Education (ASCED) code: 0399. This grouping makes the data very coarse and difficult to determine the exact demographics of graduates in Biomedical Engineering. ASCED Code 0399 contains both fields of Engineering that lead the way in terms of female participation in the US; Biomedical and Environmental Engineering (see Figure 2). This perhaps partly explains the higher female participation (16.9%) attributed to this group in the ABS census data as per Figure 2.

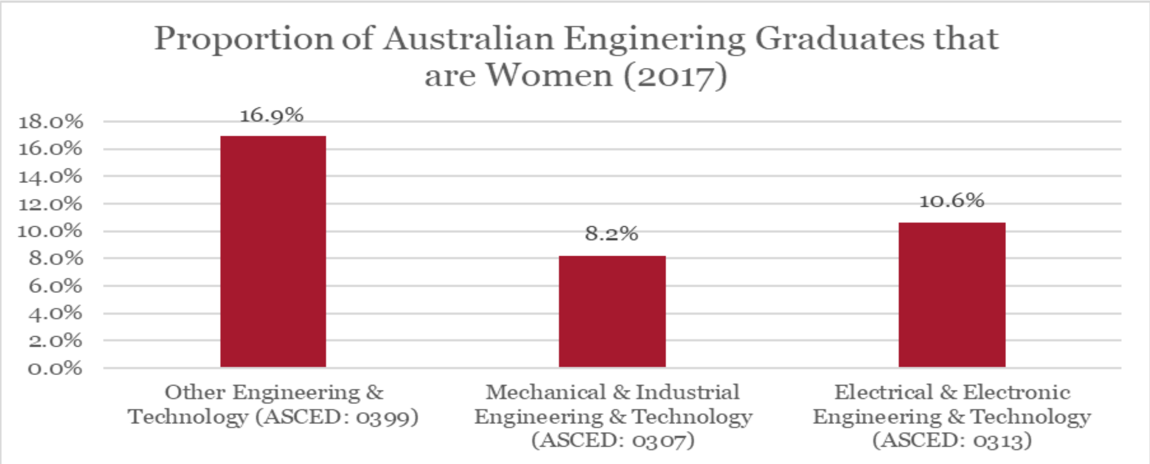


Figure 2—Female participation across Engineering Fields (ABS 2018a).

The University of Sydney produces the largest number of Biomedical Engineering graduates every year and as of 2019 reported greater than 50% female participation across their varied Biomedical Engineering courses (University Of Sydney 2019).

Perhaps a more accurate measure of the gender split in Biomedical Engineering is the number of individuals who identified as working within Biomedical Engineering in the 2016 Census. As per Figure 5, the proportion of females working as Biomedical Engineers across Australia is 35.9%. This figure is much higher than the 16.9% of graduates given by analysing ASCED code 0399.

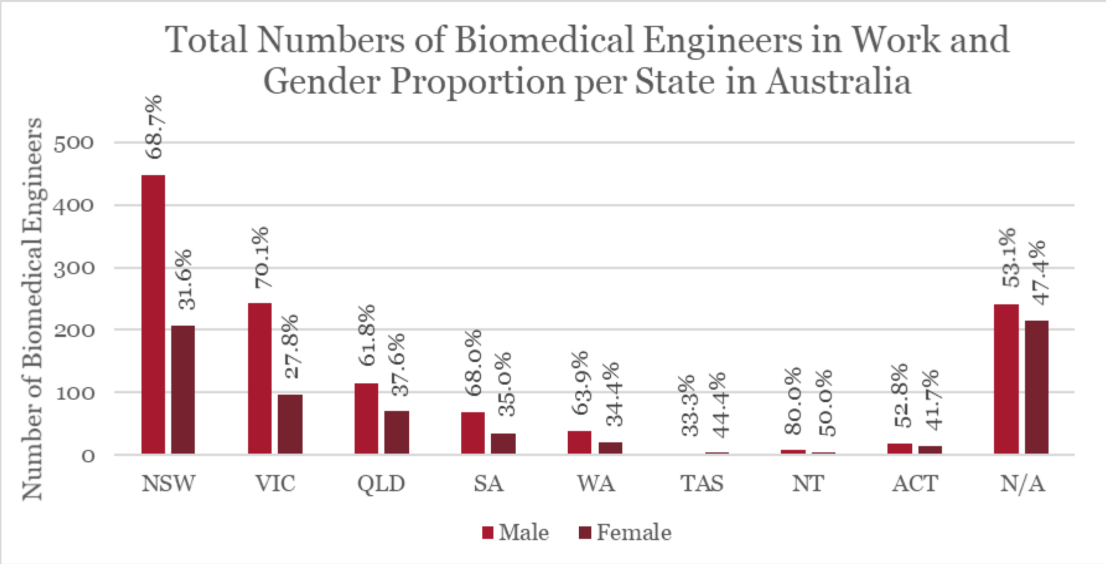


Figure 5—Men and Women working as Biomedical Engineers across Australia (ABS 2018a).

While the broader engineering fields continue to be male dominated, BME is leading the way in recruiting women. All engineering fields are equally accessible for females so the question must be, why are women choosing BME over other disciplines? The answer stated by Gutierrez et al. (2017), Murthy (2018) and Strimel et al. (2018), relates to the nexus between BME and "*helping people*" (Gutierrez et al. 2017) and the "*social responsibility contexts of care provided by BME*" (Strimel et al. 2018). While many engineers choose their profession hoping to help society achieve bigger, better, faster and more efficient objectives, BME is uniquely placed as a field of Engineering that explicitly aims to help and care for people. Pat supported this view.

Pat: *"it is a very popular topic, and there's [sic] very interesting statistics that comes out of biomedical engineering. Not just in our university, but across many others, there always tends to be equal or more numbers of female students to male students. That only happens in bio, among all other engineering, and we are about 50 per cent engineering. That's because there are a lot of female students that are now very well taught and educated in STEM, so they have a stronger interest in engineering. They see bio as an area that they can associate with, because it has very, I guess, human facing end of people, and still tap into their biomedical, or their engineering and STEM education and interest."*

In effect, the unique crossover between Science, Technology, Engineering and Math (STEM) and the direct interaction with people and health inherent in BME careers offers an exciting opportunity for more women to consider BME as a fulfilling career choice (Strimel et al. 2018).

As one female interviewee explained:

Jamie: *"I wanted to work closely with clinicians and patients, and I wanted to be on that end of actually seeing the people that I was trying to improve. I didn't want to be stuck in an industry working on some device and never actually seeing the end user or the benefit."*

Competencies and capabilities required for BME in NSW Health

Engineers Australia publishes core competencies that apply for every stream of engineering. These are very well defined and are separated into three stages as outlined in Appendix C: Engineers Australia Competency Standard for Professional Engineers (Further Information on Competencies and capabilities required for BME in NSW Health). The Engineers Australia competencies have a very technical focus. Interviewees noted both technical and soft skills when discussing the competencies required. In regard to technical skills, the key required engineering knowledge and skills include electrical engineering and mechanical engineering and knowledge of physics and pneumatics. However, according to one interviewee there are currently no published competencies which specifically relate to BMEs or the BME workforce.

The South West Sydney Local Health District states on its careers website (District 2015):

> *"To obtain an initial position in the field, a bachelor's degree in engineering is required. This is then followed by on the job training in your particular field. Many biomedical engineers will then also complete postgraduate qualifications (Masters or Business) part time while working. Engineers Australia offers advanced levels of membership that indicate a high level of professional attainment."*

The knowledge that sets BMEs apart from other engineers and which makes them a valuable asset in a hospital setting is that of anatomy and biology, and also understanding the regulations and ethics set out by the Therapeutic Goods Administration (TGA) that apply to medical devices.

Alex: *"An understanding of the device then goes back to the understanding of the actual human body to say which organ are we trying to work with and what does the organ do, and what the organ does in relation to the other organs. You need to have that comprehensive understanding of how the human body system works."*

Several interviewees stressed the importance of general problem solving and trouble shooting skills as necessary to be a successful biomedical engineer in health.

Sam: *"In my site alone there's probably 1100 different equipment types we look after, so you're never going to be trained on even 10 per cent of it. So, you need really good generic troubleshooting skills and an understanding of what the device does, what's happening with the patient."*

In addition, it was suggested that when trouble shooting a problem in a room with a patient the BME not only needs to possess technical knowledge to address device issues, multiple services feeding into equipment, breakdowns, and unusual interference problems, but also good conceptual understanding of how each of the different systems work to be able to get root cause of any technical problems. In addition, they need a heightened awareness of other factors occurring in the room, including emotional and/or aggressive visitors.

Increasingly, there has been an emphasis on the need for BMEs to possess and deploy soft skills to enable value to be added in health settings. "*Many of those interviewed*" by Hayhurst (2016) for an article on careers in health technology in the US stressed that "*soft skills are no* *longer optional*." One trainer argued that that the "*stereotypical biomed*" who "*tends to want to just fix equipment and not have to deal with people*" has to refocus attention to customers. According to Donald Gillespie of Cone Health in the US, people skills could not "*be emphasized enough*." As biomedical staff are "*no longer working with just*" their own biomed teams, they "*have to know how to communicate with people from other departments*" (Hayhurst 2016). Andrew Currie, Director of CE at The Johns Hopkins Hospital in Baltimore said that BMEs/CEs had to show that they are "*capable of fixing complex issues with medical equipment … can save money for the hospital … can work independently*", be "*good with project management … have the communication skills to train other people and work as part of a team*." Similarly, Carol Davis-Smith, Vice President of clinical technology with the American integrated managed care consortium, Kaiser Permanente in California commented that professionals in this field needed strong collaboration and critical thinking skills because "*nothing is black and white anymore*" (Hayhurst 2016). Hence, Shelly Crisler, BME with the Veterans Health Administration Centre for Engineering and Occupational Safety and Health in St. Louis, predicted that over the next decade the BME/CE profession would need: Exceptional communication skills; Prioritization skills; Technological proficiency including understanding: "*programming languages, computer networking, and cybersecurity … technology functionality and how it is used to address clinical/patient needs… interfaces and work with multiple complex systems that connect to each other … the need for patient safety.*" Moreover, she stressed that BMEs/CEs would need to be able to interpret and manipulate "*big data*", and "*know how to network even the simplest devices, because everything will store data*", as well as have an "*understanding of cybersecurity and interoperability … interfacing, as telehealth systems and wearable technology is likely to increase, and its data may be transmitted to clinical hospital systems.*" Finally, she also highlighted the need for skills to enable the management of "*technology outside of the traditional hospital environment, as patients will increasingly rely on this technology in their homes*" (Hayhurst 2016).

Similar points were made by interviewees for this project. Project management, time management and general organisational skills were highlighted as critical for meeting deadlines. The capacity to communicate with other clinicians and patients was identified as particularly important. Frankie argued that this was critical for the transition of care from the hospital setting to the home, which will require BMEs "*to spend more time out on the road potentially interacting directly with patients and acting as that mediator between patient and clinician*." Relatedly, several interviewees also raised the growing importance of IT skills for BMEs, given that medical devices are increasingly connected to hospital IT systems thus blurring the line between engineers and IT in hospital settings. For an interviewee who teaches a course on healthcare information systems, bioengineers of the future "*will need to understand enough about these information and data flow within the hospital to help - or to facilitate better workflow management, better workflow processing, and even modelling to some sense*." Frankie argued that "*the understanding of IT, of networking and how different devices operate as a system rather than standalone pieces of equipment is becoming more and more a requirement*" and Sam argued that the overlap between BMEs and IT was increasing daily.

Sam: "*from hosting our patient monitoring networks on corporate infrastructure within the virtual environments or whether it's interfacing to a medical record capture type system, those sorts of interfaces. Then clinically we need to be able to apply that within the clinical environment.*"

These changes can have implications for procurement:

Morgan: *"Sometimes it works well, sometimes it's almost open warfare. Well not so much open warfare but there was an example a few years back in a hospital in NSW for example, where the hospital needed a new ECG machine to record the electrocardiograph off patients [and] the information on which machine to buy wasn't made by the clinicians, wasn't made by the engineer, it was made by the IT department because that was the easiest machine to interface to our IT systems."*

IT systems also raised concerns relating to cyber security.

Morgan: *"well there's two ways to look at it. From a hospital IT department for example, it's all about information security and being about the transmit the information securely. From an engineering point of view, it's about information interchange between equipment, between equipment and computing systems and those sorts of things."*

For some the transformation of medical devices into e-health through AI technology and the increasing uptake in the healthcare system is particularly challenging. Speaking of the change, Andy commented:

Andy: *"I see it's coming like a tsunami. … I find it challenging every time I have to coach my colleagues in ICT, saying that you cannot treat a medical device as a computer in your office. This is a life critical device. Even though it needs to connect to your service. The turnaround time, the KPI, is totally different."*

What are the required duties and functions of the biomedical engineering workforce in NSW Health?

Biomedical Engineers, often interchangeably called Clinical Engineers (CE) or Medical Engineers, are typically assigned to manage medical devices in healthcare facilities. Clinical—or Biomedical Engineers (as referred to here)—are generally considered a BME specialisation. Whereas by some definitions, BME is practised primarily in academic institutions, the research laboratory or design and manufacturing, it appears that 'Clinical Engineering', is the preferred title for the work undertaken in hospitals and other environments where medical device technologies are used.

The American College of Clinical Engineering defines Clinical Engineering as "*an interdisciplinary field practiced in a variety of settings and presenting a diversity of challenges. The clinical engineer is, by education and training, a problem solver, working with complex human and technological systems. In American hospitals, as in private sector firms, clinical engineers often function as technology managers for medical equipment systems with responsibilities for financial or budgetary management, service contract management, data processing systems for managing the medical equipment, and coordination of service agreements and in-house operations.*" In addition, in hospitals they may also be responsible for supervision of the in-house maintenance staff and for ensuring that the medical equipment is safe and effective. "*These functions include participation in the planning process and in the* *assessment of new technology, assuring regulatory compliance in the medical technology management area, investigation in incidents, and active participation in training and education of technical and medical personnel*."

BMEs take care of medical devices throughout their life cycle within healthcare facilities, managing not only medical equipment, but also implantable medical devices, in order to safeguard patients' lives. They may also train clinicians, nurses and other professionals working in health-care facilities to ensure the best and safe use of medical devices. In addition, they are generally expected to work across different levels of health-care facilities (Hayhurst 2016). As such, BME's often participate in the planning of areas or new units of hospitals, as well as in the planning of health-care facilities, to support the decision making relating to medical technologies requirements depending on the clinical interventions that would take place in response to changing population needs.

The NSW Health South Western Sydney Local Health District careers website highlights the following tasks and responsibilities as core to the role of a Biomedical Engineer (Recruitment 2015a):

- Calibrating and commissioning of all types of medical equipment and systems including: Patient Monitors, Defibrillators, ECG machines, X-ray units, CTs, and MRIs
- Providing advice and support during selection and evaluation of new equipment
- Ensuring safety of patients, staff and the general public
- Research and Development - to improve equipment for delivering care
- Teaching other engineers and technicians and other hospital staff, both specific and general.

According to the American College of Clinical Engineers (ACCE), a clinical engineer "*is a professional who supports and advances patient care by applying engineering and managerial skills to healthcare technology*" (ACCE 2018).

This site explains that:

> *"As clinical medicine has become increasingly dependent on more sophisticated technologies and the complex equipment associated with it, the clinical engineer, as the name implies, has become the bridge between modern medicine and equally modern engineering."*

The key here is that the focus of Clinical Engineering is healthcare delivery, it is operationally focused as opposed to research focused. Apart from these terms, another term that reflects activities undertaken within NSW Health is Healthcare Technology Management. The Association for the Advancement of Medical Instrumentation (AAMI) identifies that:

> *"Healthcare technology management (HTM) is the name of the field responsible for managing the selection, maintenance, and safe and effective use of medical equipment and systems. This field includes biomedical equipment technicians (BMETs), clinical engineers, imaging equipment specialists, laboratory equipment specialists, and others who protect patient safety and reduce healthcare costs related to technology" (AAMI 2017).*

A commonly used term by interviewees is that BMEs form a 'bridge' between multiple stakeholders throughout the health system. The schematic in **Figure 3** shows how the BME or CE acts as the hub of a wheel, in which a broad spectrum of stakeholders interact.

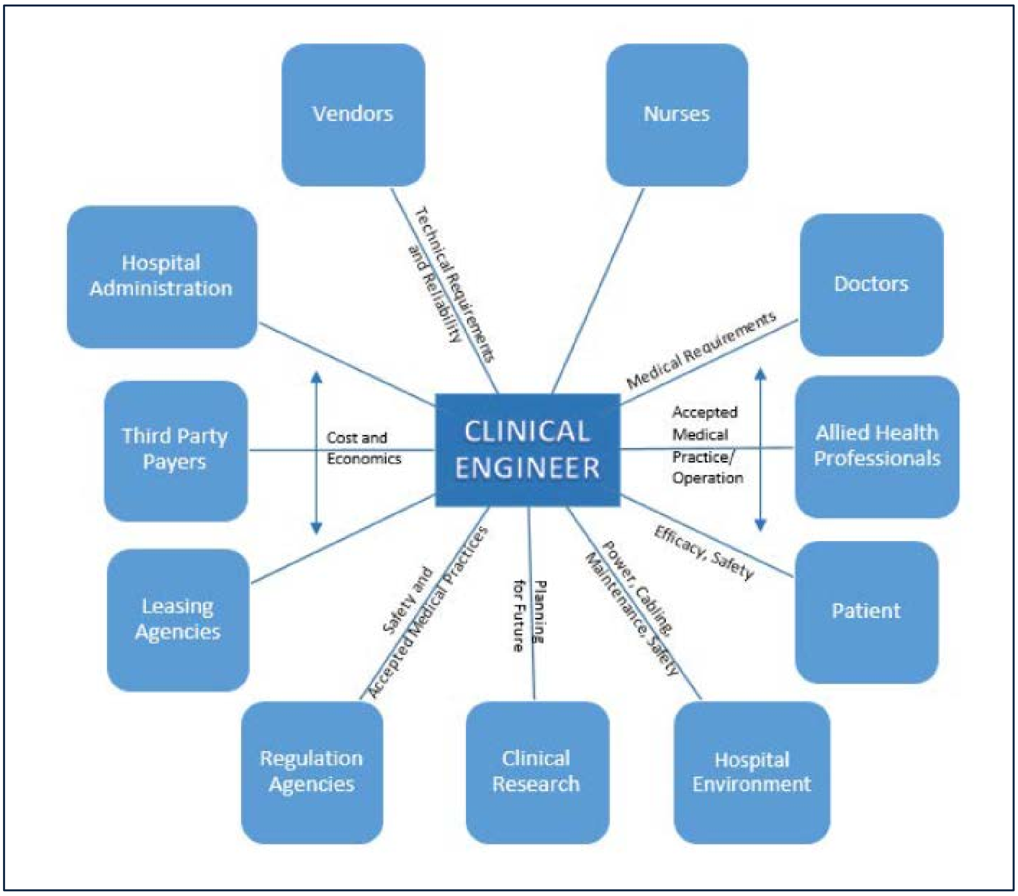


Figure 3—The various stakeholders throughout the health system and how they interact with BMEs/ Clinical Engineers (WHO 2017).

Interviewees provided various accounts of the types of duties and functions performed by BMEs in NSW Health. The role of clinical engineer, occupied by the largest number of BMEs in Health, was described as applying biomedical engineering principles in the healthcare setting and some considered that many activities can be described as health technology management. Overall, the TGA largely determines which technology/ equipment is managed by BMEs.

On a day-to-day basis, this entails managing the technology that is used in clinical procedures, including defining requirements in conjunction with clinicians, procurement, managing, maintaining and decommissioning devices, handling alerts and recalls, as well as being involved in training and application. Drew pointed out that "*Health technology management is a very descriptive term to use for cradle to grave management of technologies used in healthcare*," which is what the bulk of biomedical engineers do in NSW Health hospitals. Morgan clarified by stating that BMEs "*look after the assets of the Health District*," including "*everything from working with the clinical staff to*" identifying "*the need for a particular diagnostic piece of kit, working through the procurement process, ensuring appropriate installation,*" maintaining "*the product throughout its working life and eventually identifying need to replace it because it's reached end of life.*" This ongoing process is done for "*everything from a simple* *examination light attached to the bed through to CT, MRI scanners and the like*." As the WHO diagram above indicates this process is linked to e-health and medical asset management processes.

Numerous interviewees also highlighted the changing relationship between BMEs and BME technicians (BMETs).

Frankie: *"So the difference between the technician and the biomedical engineer, I'd say traditionally the technician is you would call a bench repair engineer or they would be doing routine testing, so where you have highly repetitive work usually being performed in a clinical setting because biomedical equipment just by nature, the scale of it, you can't bring everything back to a central location."*

As Andy put it: "*Benchtop repair under biomedical engineering is a thing in the past. System management is current*." The views of our interviewees echoed those interviewed by Hayhurst in the US. As Scott Nudelman, General Manager of biomedical services for GE Healthcare in the US commented, twenty years ago, biomed "*was still part of facilities management. To be a good BMET, you needed electromechanical skills, a good understanding of device clinical applications, and an adequate library of service manuals*." Now, however, "*as things have become more software driven and IT-centric …there's less and less stuff that a biomed can actually fix, and it's more about literally being that manager of healthcare technology*." As a result at GE, where "*98% of the service work*" was previously done inhouse, outsourcing has increased "*because of proprietary service software or supportability issues*" (Hayhurst 2016).

Several interviewees also identified another type of BME found in hospitals, notably the rehabilitation engineers who form a relatively small cohort but who were nevertheless identified specifically as those who, according to Morgan, "*assist people with disabilities … everything from customising, custom-making wheelchairs to walking frames*" for those "*people who have had injury and they have to learn to walk again*." As Drew commented about this "*very small specialist group:* "*If there is 300 biomedical staff working in NSW Health hospitals, the number of rehab engineers would be less than 10 … there's pockets of them work in some specialist areas and that's about it. Not mainstream at all*."

Two other specialist BME roles were identified as being present in NSW Health, notably those who specifically cater to the home dialysis patients and the radiation oncology biomedical engineers, which Andy described as "*a frontline support team*" which helps radiation oncology departments to maintain or to service their linear accelerators used for radiation therapy for cancer patients in certain locations.

BMEs also play a role in procurement and managing the tenders and contracts with the Original Equipment Manufacturers (OEMs) in cases where maintenance of large specialist biomedical equipment is outsourced. HealthShare is the state-wide department of NSW Health that manages large contracts. Andy noted that HealthShare is a big organisation which encompasses an electromedical subgroup that is responsible for tender contract management and procurement. Alex also commented that BMEs working in HealthShare could engage in the procurement process.

There are also small numbers of BMEs who carry out research functions funded by research grants and often engaged on clinical trials. It is unclear whether these research focused BMEs are those identified under Medical Laboratory Scientist ANZSCO Code: 234611 whose work is defined as: conducting medical laboratory tests to assist in the diagnosis, treatment and prevention of disease.

Jamie: *"They can provide research to develop into new technologies and new devices and, like I said before, patient-specific devices and work closely with surgeons and other clinicians in developing new technology that's going to suit them. Because in a research lab I also work closely with engineers in my research lab, and one of their roles is to work closely with surgeons on developing implant devices. So, they're not employed by NSW Health. They have research positions, but they are working closely with surgeons and people in the hospital and have access to patients' imaging and data to develop implants."*

Drew: *"Even within a health department, there are research pathways as well. So, there are biomedical engineers that work closely associated with clinical departments doing some – you know, some fairly basic sort of research and working side by side with clinicians … It's not huge but it is there. There's increasing areas of activity, such as, you know, implant technologies and 3D printing, or adequate manufacturing of implants and that sort of thing, so you know, there's areas like that that are emerging that are being explored."*

The diversity of BME duties in NSW Health was demonstrated by Jamie, a BME who is classified as a 'hospital scientist'; who performs a quite different role to the mainstream BMEs in NSW Health by undertaking three-dimensional gait analysis for patients involving "*operating, processing, retaining and testing and doing the calibration of a range of measurement and equipment … processing and the interpretation and then presenting that report to the referring doctor*" and working closely "*with the support engineers for the service equipment*" particularly in regard to upgrading.

Is there an optimum number of biomedical engineers per Local Health District/ Speciality Networks? What determines need?

To date, there is no single broadly accepted or accurate model to determine appropriate staffing levels for Clinical Engineering Departments (CEDs) (Miguel-Cruz and Guarín 2017). There are a number of different metrics or methods that have been developed by various organisations around the world to answer this question.

According to Miguel-Cruz and Guarin (2017), data from the American Association for the Advancement of Medical Instrumentation suggests that the most important factor that determines the required number of Full Time Engineers (FTE's) is the total number of Technology Management hours (TM hours), whereas hospital complexity (estimated based on hospital discharges) is inversely correlated.

Equation 1: Calculation for Total Full Time Equivalent BMEs. Source: (Miguel Cruz and Guarín 2017).

$$ToT_{FTE} = -91.60 + 6.45 * \ln(ToT_{Devices}) + 9.99 * \ln(ToT_{TM_{hours}}) - 2.84 * \ln(HCO\_Discharges)$$

More than one interviewee referred to commonly used rules of thumb, such as for every 300 or so medical devices, at least one BME is required. Andy calculated it by beds – one BME for every 100 beds, while Drew preferred the cost of service ratio metric used globally.

Interviewees identified a number of factors needing to be considered in deciding the optimum number, including the quantity and types of services and devices, the objectives of the Local Health District, and the level of equipment outsourcing. However, Alex noted that "*there's no standardised way of approach as to how many people we would need per how many devices and the kind of work we do*", and that each Local Health District had its "*own way of doing things*". Frankie concluded that it "*depends on what outcome you want to achieve. So, there are very different philosophies in the way that equipment is managed and maintained*."

One study focused specifically on 'outsourcing versus in-house maintenance' found that the closure of in-house Clinical Engineering Departments in healthcare institutions was based on the assumption that externalising maintenance services improves both maintenance quality and saves costs (Miguel-Cruz et al. 2014). However, this study concluded:

> *"In public health institutions, internal governance shows better performance than external governance; this suggests that healthcare managers should reconsider the trend to eliminate in-house maintenance service staff in public healthcare institutions" (Miguel-Cruz 2014, p193).*

This conclusion suggests that the outsourcing approach to maintenance neglects to factor in the hours of paperwork required to manage the externalised maintenance, which generally falls to an inhouse BME to complete. Adrian argued that work done inhouse was "*more cost-effective than outsourcing it.*"

What is the role of technicians when working with biomedical engineers?

Hunter New England Local Health District (HNELHD), a district within NSW Health, defines the primary purpose of a Grade 1 Biomedical Technician is to:

> "*Maintain medical equipment across HNE Health by providing repair, testing and preventative maintenance services; document all services; and provide in-service training to clinical staff* " (Position Description 2019, https://jobs.health.nsw.gov.au/hnelhd).

The following accountabilities are outlined in the Position Description:

- Repair medical equipment – broken medical equipment hampers the delivery of patient care and so it is essential that equipment be repaired in a timely manner

- Test medical equipment for safety and function to AS/NZS-3551:2012 to ensure patient safety and correct diagnosis/treatment
- Perform preventative maintenance procedures on medical equipment which requires regular servicing to ensure patient safety and correct diagnosis/treatment
- Provide in-service education for clinical personnel to assist the clinical staff to look after medical equipment and to use it correctly
- Document all work on the HNE Clinical Technology's equipment management system (EMS) to provide service
- Act in accordance with the HNE Health Values Charter and NSW Health Code of Conduct; model behaviours that reflect the Excellence Framework (Every Patient, Every Time) and ensure work is conducted in a manner that demonstrates values of cultural respect in accordance with HNE Health's Closing the Gap strategy
- All staff are expected to take reasonable care that their acts and omissions do not adversely affect the health and safety of others, that they comply with any reasonable instruction that is given to them and with any policies/procedures relating to health or safety in the workplace that are known to them, as well as notifying any hazards/risks or incidents to their manager.

The South Western Sydney Local Health District separately defines (Recruitment 2015b) the core role as involving:

- Calibrating and commissioning of all types of medical equipment and systems including Patient Monitors, Defibrillators, ECG machines, X-ray units, CTs, and MRIs
- Providing repairs to complex medical electronic and electromechanical equipment
- Testing devices to ensure safety of patients and staff
- Building novel devices for improved patient care.

Currently, in NSW Health, the distinction between the biomedical technician and the biomedical engineer is not clear cut. As a general rule, the technician is TAFE qualified and the biomedical engineer is a university graduate. However, in terms of job title the majority of technical officers are now graduates and the BMETs who have been there for a long time are typically trade rather than degree qualified. In comparing the two in terms of roles or duties, the level of complexity in the tasks of the engineer are greater than the technician. The point was made across interview participants that the technicians and engineers work closely together and have similar salary levels. As noted earlier, Frankie suggested that traditionally the technician would do the routine testing "*out there on the floor*", as well as basic repairs at the bench in the biomedical engineering department.

Interviewees' suggestions for the future are as follows:

- technicians need to start to learn how to manage multiple contractors as part of change of business process and practice in the healthcare system in order to deal with increases in the quantities of repairs
- expand the role of BMETs to encompass testing performance verification, the servicing and repairs of the devices, leaving higher level type work in management, the asset management, risk analysis, assisting with procurement, resolving complex issues, getting involved and providing solutions for clinicians, problems to engineers
- introduce dual classifications enabling employment as either professional engineer or technical officer
- ensure routine testing and basic repairs in the biomedical engineering department are performed by BMETs overseen by BME manager
- respond to longer Original Equipment Manufacturers (OEM) warranty periods and less maintenance intensive work for technicians by using BMET expertise in the field addressing clinical outcome needs through appropriate technologies rather than fixing machines.

What other support workforces carry out the work that biomedical engineers also do?

The work conducted by the OEMs depends on the priorities of the Local Health Districts/ Specialty Networks (LHD/ SN), the type and complexity of the device, with more specialised and high value equipment being more likely to be outsourced, and the number of BME staff available in the hospital. The reliance on OEM and on outsourcing elicited a range of contrasting perspectives from different interviewees.

Frankie: *"I'm seeing LHDs and OEMs actually coming closer together on this. So, OEMs always had the intention to maintain as much technology as possible as they could. Because it's another revenue stream for them. But what they've quickly realised is it's also a very expensive service delivery model. So, I think we are coming to a happy medium where OEMs are realising that it is best for the biomed teams to maintain the equipment from a frontline perspective and for then the OEMs to step in when specialised support is required. So I think as we move forward there will be a need for a more collaborative approach between biomed and OEM and this is going to require a culture shift especially with those biomed departments that have this vision of doing everything in-house … As the technology becomes more proprietary and more IT focused that will be harder to do."*

Sam: *"Again there's significant variability across the State. In my part of the world very little gets passed on, so we look after the majority of our stuff in-house. We have contracts on a couple of … high value capital equipment or major medical equipment, … the type of piece of equipment that is built into a room, rather than wheeled into a room. Pretty much all of that will be on a contract. To train someone to service that it's going to cost me a whole lot of money and the* *following year they'll have very lucrative job offers, paying far more than what I can afford to pay, and secondly, I can't afford to have millions and millions of dollars of stock on my shelf. In terms of the stuff that we look after, it tends to be the stuff that can be wheeled in or moved in and out of rooms. For that sort of equipment there's probably only a couple in my area that we would have on an outsource basis. Occasionally you'll get the odd vendor come along and they'll have a very good fixed price repair deal, so we'll still do all the diagnosis and we'll do the comparison. If I bought in these two boards and top case it's going to cost me this much, they've got a fixed price repair for this, you know it doesn't make sense. The vast majority for us is looked after in-house."*

The advantages and disadvantages of outsourcing were also considered by the interviewees. Advantages include lower in-house overheads and risk management.

Frankie: *"You are also outsourcing all the risk, so the advantage of the outsource model is that one, you don't carry the overheads in-house … you are really then contract managing from that point onwards."*

However, the disadvantage is the time it takes to have an OEM come on-site to repair, and for some medical equipment, repair can be time critical. In order to get around this, some LHD/SNs carry spare units.

Frankie: *"There are ways to deal with that. So, I've seen LHDs where in order to combat that they may carry some loan units where they can swap equipment out until the OEM comes to perform the repair."*

According to Pat, while the introduction of new biotechnology should be done by engineers, they can be supported by nursing staff particularly in the use and application of biotechnologies and in relation to telehealth and associated administration such as capturing activity, patient concerns, scheduling.

In light of the increased blurring of lines between BME and IT, noted above, Andy noted that in some cases BME Departments are managed by Chief Information Officers, some of who have BME backgrounds.

What other clinicians contribute to service delivery with biomedical engineers?

BMEs provide a support service to other clinicians in hospitals when there are problems with the medical devices being used by clinicians. According to interviewees, experienced front-line clinicians will often troubleshoot a problem with a medical device, and if it is not easily solved, will alert the BMEs to have it repaired or replaced. In this regard, one interviewee estimated that for 15 to 20 per cent of the time the clinician will be able to solve the problem, but the rest of the time it will come to the BMEs, an issue that was not referred to in the literature. Based on the interview data, it would appear that BMEs work closely with other hospital clinicians to identify the latter's needs and to help them find the most suitable technological solutions. Once clinicians identify a clinical problem expressed in clinical terms, the BME's role is to understand, interpret and solve that problem. As a result, a number of interviewees commented that BMEs and clinical staff work best when the they are considered as peers in the process of identifying the best equipment for specific clinical needs.

Are there other ways that a biomedical engineering workforce could contribute to the work of NSW Health?

A report undertaken on the role of BMEs in the National Health Service (NHS) in the United Kingdom (UK) identified that engineers and technicians have the potential to play a significant role in relieving the pressure on stretched clinical staff, resources and budgets. Meese (2016) reported that the barrier to the expansion of this role and its contribution to health and care, is the lack of prominence of this speciality and the lack of value accorded to it. According to Meese (2016) the presence and significance of BMEs is often unclear, inadequately recognised and poorly understood by other NHS sectors. Meese (2016) and WHO (2017) both argued that for cross-disciplinary working to be successful within health services, the skills of biomedical engineers in health need to be understood as a distinct discipline that offers significant value to patients, hospitals and the national economy.

As noted throughout the foregoing, the contribution of BMEs is changing and there are new opportunities for BMEs to contribute to the work of NSW Health. Three key opportunities to be discussed here are: (i) an expanded role in terms of design and development, (ii) aiding the implementation of system networks by working collaboratively with ICT and (iii) greater standardisation in service delivery across NSW. All three have the potential to improve the effectiveness and efficiency of NSW Health service delivery and patient care.

As outlined by Meese (2016), expansion of the BME's role requires recognition of the value they can contribute to NSW Health beyond just repair and maintenance of medical equipment. As Frankie stressed:

Frankie: *"We've got to operate beyond our comfort zone I think, and we've got to look at ourselves as a key component of delivering care rather than maintaining technology because the maintenance of the technology as it is today, won't be that way in five or ten years but delivering care to patients will always be here. So, we've got to find our way to add value in the patient care delivery process."*

Several interviewees referred to the underutilisation of BMEs by NSW Health and pointed to the opportunity for BMEs to be more innovative in developing clinical solutions. Given the knowledge and training that biomedical engineering graduates bring to their roles, they are well placed to make a wider contribution to improved health service delivery.

Pat: *"Biomedical engineering should be doing a lot more than what they are asked to do. I'm just talking about from hospital level. If NSW Health needs biomedical engineers as an innovator, or as someone who can bring technologies to really modernise and disrupt how we are using, or we are providing services, I think that would be really great. At least giving them that impression, would be very important for our community."*

Blake: *"Biomedical engineering as a discipline has come a long way now, and therefore the biomedical engineers, with the help of computers and the new type of materials and all that can certainly be ahead of clinicians. In the ideas, the development. Because see, now we have new fields in systems biology that really are trying to model all biological actions into very complex system approach. Like, engineers are well used to do that."*

A Report produced by The McKell Institute in 2016 argued that the TGA is not keeping pace with equivalent regulatory bodies, needlessly slowing down the development and approval process (Hine 2016). Alongside the regulatory constraints and strict use conditions as part of obtaining TGA approval and staying within the guidelines, interviewees also identified the risk-averse culture of NSW Health as a factor hindering more innovation.

Some ways in which NSW Health could support or encourage this innovation in-house would be through innovation hubs, centres of excellence, and research grants targeting internal projects.

Charlie: "*One way of actually creating a research and innovation environment which really covers the huge range of possibilities, is actually to create one or more centres of excellence, let's call them, in health engineering. Which are co-owned by the health system and by the universities."*

In the US, Johns Hopkins University has an innovative post-graduate course for BME students, which involves partnering with clinical teams in the healthcare sector (Yazdi 2013). While it is very start-up oriented and potentially particular to the US culture, it highlights the interest by clinical teams in getting engineering expertise to innovate and the skills and knowledge that BMEs can bring to these teams. This model was particularly well received by Charlie because, despite being a small course of about 30 students, "*the number of patents and spinoff companies that it generated were staggering … Something like 25 per cent of the students ended up with a successful start-up*."

According to Deloitte Access Economics (Snyder 2015, Economics 2015), network connectivity is one of five key building blocks to the technological progress that is driving innovation in medical technology. The developments made possible by this connectivity and the associated data "*can allow companies to create new products that deliver significant benefits to patients whose conditions had previously been difficult to treat or manage*". BMEs play a critical role in the selection of these devices and implementation on to network systems in hospitals. This new environment means IT departments and BME departments need to work collaboratively together in selecting and managing new medical technology.

Frankie: *"I think that the design of the device, of the technology will always be a separate component but applying those design principles to the system with a capital S, is an opportunity for us because that now starts to talk about how do we integrate different components of the system, and we haven't done that very well until now. And we are going to be forced to do it because we've been able to get away with practising in a silo because it was, if it's a medical device then we deal with it but it's no longer just a medical device, it's now a system, it's a collection of devices delivering one outcome. And so being able to understand, how do all of these different systems interrelate and act with one another I think is going to be* *opportunity for us to apply that system thinking and those design principles to healthcare overall."*

Numerous interviews commented that the lack of centralisation limits the ability to tap into the BME workforce at a state-wide level. Accordingly, it can be argued that there is potential for BMEs to add greater value to NSW Health through the adoption of a more formalised structure across the LHD/SNs, such as a central unit or channel, that could enable better utilisation of the BME workforce, increase their visibility throughout NSW Health, improve career training and opportunities for BMEs and make it easier for other areas to work with BMEs on state-wide projects.

Frankie: *"I'm starting to sense a lot more of a move towards standardisation. One thing I've always asked myself is every hospital has a biomedical department, every hospital has a biomedical workshop, is there any opportunity to start bringing some of these teams closer together and helping one another. I also think that there's a really big opportunity to better use our workforce, so we can't all be busy at the same time every day, is there an opportunity to have a workforce that's more mobile, that can move around from one LHD to the other depending on the demand in that LHD? Today we seem to be very much restricted by the borders of that Local Health District and don't venture beyond that. But if we look at ourselves as a pool of X number of people across the state rather than five or ten at every hospital, I think we are going to leverage the scale a lot better than what we do today."*

Charlie: *"There's also an issue that they should be thinking about which is that given a state government agenda in generating and building and sustaining a large device industry, at the moment the interface between industry and the hospital system is individual biomedical engineering departments and individual clinicians, to a large extent.*

Is there a role for some more centralised structure, and I use that term with great care, where at least there are some core components of biomedical expertise? They could look across the system and say, well okay in all of our LHDs there is this problem, we will sit down and work out what kind of thing needs to be done and go and talk to the relevant stakeholders in the industry about what they can do to fix it."

Morgan: *"I came out of the central engineering service in Western Australia, we were located in Perth, but we had 102 clients scattered right across the State. So, there was a central service and it was a reasonable size service. Queensland has the same. When you get to that sort of size you can deliver things like on the job training, career enhancement and things like that. When you are three people in the basement of a hospital you don't have that ability."*

A move toward greater standardisation and centralisation, as well as BME involvement in state-wide projects, would also create a need for a governance framework to be in place in NSW Health to ensure more effective means for BMEs to contribute to such projects. In Queensland, the State Government registered 'Biomedical Technology Services', which operates as a business (ABN 66329169412) provides a central headquarters for managing service requests with service locations in most major hospitals. This approach could provide a means for addressing the current diversity in service delivery, operations and reporting across LHDs in NSW, maintaining technology in hospital settings and running a state-wide projects.

Training pathways and qualifications for biomedical engineers working in NSW Health

What qualifications are required to become a biomedical engineer working in NSW Health?

Biomedical/Clinical Engineer

The South West Sydney Local Health District states on its career's website:

> *"To obtain an initial position in the field, a bachelor's degree in engineering is required. This is then followed by on the job training in your particular field. Many biomedical engineers will then also complete postgraduate qualifications (Masters or Business) part time while working. Engineers Australia offers advanced levels of membership that indicate a high level of professional attainment. The level of Chartered Profession Engineer can be achieved by those who have had sufficient on the job training and experience, approximately 5 years after graduation. The attainment of Chartered membership is recognition that you have enough knowledge and experience to take on significant responsibility in a department."*

There is currently no requirement in NSW for registration or licencing of BMEs. Several interviewees saw a need for a registration program in NSW, as operates in Queensland where BME's register with the Board of Professional Engineers of Queensland following assessment by Engineers Australia (https://www.bpeq.qld.gov.au/) (BPEQ 2019).

As the official website of Business and Skilled Migration Queensland Unit of Trade and Investment Queensland has noted since February 2018:

> *"It is a requirement of the Professional Engineers Act (QLD) that professional engineering services in Queensland or for Queensland are carried out by a Registered Professional Engineer of Queensland (RPEQ) or alternatively by a person who carries out the services under the direct supervision of a RPEQ who is ultimately responsible. Queensland is currently the only Australian jurisdiction to apply a comprehensive registration system for engineers. However, other states are said to soon follow suit. There are currently 26 areas of engineering recognised by BPEQ. BPEQ works with professional organisations to define these areas of engineering, which range from aeronautical to civil engineers, chemical to naval architects. The registration system ensures a high standard of practice exists within Queensland across all areas of engineering" (BSMQ 2018).*

Registration at the State level is a different approach compared to other countries, such as Canada, the Czech Republic, Taiwan, and the US where national registers are maintained (Medvedec 2014). Such registers provide greater recognition of the value of BMEs in their workplaces, a standardised minimum level of qualification and alignment with other technical workforces, such as civil engineers in building construction, electricians, plumbers, etc. A number of interviewees expressed concern about this issue. Speaking of NSW, Adrian commented that there was "*currently no requirement to be licenced or registered or have any minimum level of competency or qualification to do biomedical engineering and work on medical equipment*," which he, Alex, Sam and Charlie contrasted with the need for electricians and plumbers to be licensed to undertake any installations. As Adrian put it: "*anyone can walk off the street and work on medical equipment.*" For Charlie, the benefit of a registration system is that it provides confidence that the BME "*has the core skills required to maintain and design a device in such a way that it is safe for human use*." For interviewees, Engineers Australia was considered as the most reputable body to ensure confidence in a licencing program because, according to Sam, it has the chartered professional engineering competencies for technical aspects of the work and competencies for stage three management. Most importantly, it can provide consistency across the country.

In NSW Health, BMEs are typically required to be degree qualified in biomedical or electrical engineering or trade qualified in these areas with industry experience. Double degree or postgraduate degree options in biomedical engineering, combined with science or medical sciences, could also make attractive candidates for NSW Health. For those applying from overseas, Engineers Australia plays a role in ensuring equivalency of degrees. This can be seen in detail in Appendix C.

Biomedical/Clinical Technician

A job description for a Grade 1 Biomedical Technical Officer for the Hunter New England Lower Health District posted on the NSW Health Jobs page (jobs.health.nsw.gov.au/hnled) in June 2019 outlined the following selection criteria:

- A qualification from an Institute of TAFE at least equivalent to the AQF Certificate level 3 or other qualification deemed acceptable by HNELHD (Certificate 3 in Electronics – Trade)
- Some experience in the repair of equipment containing digital and analogue circuits
- Demonstrated computer skills including the ability to use common word processing presentation, spreadsheet and database tools.
- Demonstrated verbal and written communication skills
- Ability to work alone and be a self-starter.

A job description for a Grade 2 Biomedical Electronics Technical Officer posted on the NSW Health Jobs page (jobs.health.nsw.gov.au) in October 2019 outlined the following selection criteria:

- Possess an Advanced Diploma in Electrical Engineering or equivalent qualification appropriate to the position

- Demonstrated high level of fault-finding skills with electronic circuits especially surface mount devices. Be able to diagnose and repair to component level. Good soldering/de-soldering techniques
- Possess strong background in IT networking principles, including ability to utilise computer software and database applications
- Be technically competent and have good knowledge of both analogue and digital electronics as applied to medical and electronic laboratory equipment
- Ability to work as part of a team and be capable of working with minimal supervision
- Advanced interpersonal and stakeholder management skills with an ability to effectively liaise with internal and external stakeholders such as nursing, medical and administrative staff and suppliers of services and components to the hospital
- Ability to adhere to a quality system and perform administrative duties with thoroughness including a good understanding of the importance of safe work practices, with an ability to ensure their own and co-workers' safety by adopting safe working practices and compliance with WH&S policies and procedures
- Current Drivers Licence valid in Australia.

For the technical support workforce, new technicians today are also likely to be degree qualified, as more undergraduate degree programs are offered and few trade qualification options are available in NSW. This, despite the fact that an advanced diploma and experience working with electronics can meet the requirements for the job. As there are an extensive number of diplomas and certificates across ten to fifteen different fields that could be considered applicable, a comprehensive listing was beyond the scope of this project.

What training programs for biomedical engineers exist in Australia?

The undergraduate degrees in biomedical engineering offered by a number of large universities around Australia provide the primary training ground for BMEs. Courses offered by different universities tend to have different foci, but all need to meet the requirements of Engineers Australia in terms of the knowledge and capabilities that graduates should have. Engineers Australia reaccredits engineering courses every five years. Please Refer to Appendix B, which provides a Table of relevant University Degree Courses.

Academic BME programs have continued to grow in number in Australia. In Sydney, for example, the University of Sydney (USyd) offers a four-year Bachelor program in BME aiming to graduate some 100 BMEs annually, whilst the University of Technology Sydney (UTS) has recently introduced a biomedical engineering major option within its four-year engineering degree. Both are in addition to the long-standing Master level concurrent BME programs at the University of New South Wales (UNSW). Elsewhere in Australia, BME programs are taught at the University of Melbourne, RMIT, Swinburne, Flinders, La Trobe, the University of Queensland, and Queensland's University of Technology. Monash University also offers a five-year Bachelor of Biomedical Science and Bachelor of Engineering dual-degree program, and other Australian universities offer programs in the related disciplines of biotechnology and biomedical science (Hine 2016).

The most important aspect of undergraduate training programs, emphasised by nearly all interviewees, was the industry placement/ internship programs as part of the degrees. Most of the university BME courses include industry placement of 12 weeks, while UTS requires six months of industry placement for all BME students. Industry placements enable students to develop important employability skills.

Taylor: *"One of the great strengths about most engineering programs is they have these placements. Most of them put students into companies or students have to find their own place to go for a six weeks or a few months or whatever; they're very good at that and of course companies, there's a lot of companies and they're very happy to take the students, but once again, the students and the staff tend to look for placements in industry, rather than I think placements in the healthcare system."*

Several interviewees commented that it was important for BME graduates to obtain internships in public hospitals if they "*want to work in public health*" because this provides *"exposure to a very wide variety of equipment*" and an opportunity to "*understand it in its applied circumstances*" with patients, as Sam put it.

Industry and hospital partnerships are also expanding beyond the traditional internship style programs to create new opportunities for students and for collaboration. At UTS for example, industries get involved in project-based subjects involving student groups and industry funded projects conducted by academics. According to interviewees, health related innovation hubs in different parts of Australia "*work with industry providers and companies on new technology*" and include programs that seek *"to match students and industry to promote development.*" In addition, Sydney University ran a program at Westmead hospital that attached a number of outstanding biomedical engineering students for a year, more or less full-time, to a clinical team to undertake their Honours theses.

For the technicians, there is currently a gap in NSW, at least for trade level training programs. One of the interviewees discussed the current online TAFE offerings and the training program run by The Medical Room, a specialised training consultancy firm operating in the UK and Australia, which is currently in the process of applying for Australian accreditation with Engineers Australia at the advanced diploma level because this is the level that Engineers Australia define engineering associates or engineering technicians. The value of this program is that it provides practical hands-on training for servicing and medical devices. In Perth, Western Australia, the Engineering Institute of Technology (the "*sister company of the reputable engineering training organisation IDC Technologies*") has delivered "*industry-driver programs for over 10 years*" and offers Australian accredited engineering Diplomas, Advanced Diplomas, Graduate Certificates, Bachelor Degrees and Master Degrees, including an online Advanced Diploma of Medical Engineering, as well as *"non-accredited Professional Certificates of Competency*" that *"impart skills that can be immediately implemented in the workplace making them ideal for ongoing professional development"* (Engineering Institute of Technology 2019).

A search was conducted for relevant vocational courses that would satisfy the requirements set out in the job descriptions as outlined above, which state a Certificate III in Electronics – Trade (or equivalent) or an Advanced Diploma in Electrical Engineering (or equivalent) respectively. There are many courses offered all over the country that would satisfy this requirement. Without further narrowing the criteria it is not possible to provide a comprehensive list of Registered

Training Providers (RTOs) for these courses. The unit of study UEENEEH134A – Fault Find and Repair Electronic Medical Equipment was explored as a method by which to narrow down the field. However, none of the RTOs authorised to administer the course (as per the Australian Government site: training.gov.au) advertise it as part of or an elective in any courses they offer.

What on the job training is provided for biomedical engineers in NSW Health?

While undergraduate training programs provide the basic engineering principles and foundational theoretical knowledge required, on the job training is critical given that hospitals have in the vicinity of 100 different types of medical equipment. As a result, it can take at least a year of employment in a hospital before a new graduate will be competent to perform their duties in NSW Health. There is no clearly established state-wide training, internship or graduate program, though specific LHDs/SNs of a large enough size do run these types of programs. Royal Prince Alfred (RPA) Hospital, for example, has recently formalised its internship program and takes three students every six months from: UTS, UNSW, and USyd. Sam and Adrian both noted that a BME degree provided a minimum level of knowledge, akin to "*a driver's licence*" on top of which other skills needed to be developed in the workplace, such as for example, how to use electrical safety testing equipment for annual testing.

Manufacturers do provide training in NSW. However, such training is device specific, and often bundled into the purchase of a machine or device. Through a Biomedical Managers' Group, established between some LHD/SNs, this may be made available more broadly to BMEs in different LHD/SNs.

Alex: "*When we work in a hospital we get - we have basic training. We have seniors who … have the train the trainers type of training. They train the others and most of the training comes from the manufacturers. When we procure devices, we make sure that we get trained. That training depends on what level of training and what sort of training the manufacturer is willing to give to us in relation to the management of the devices. Based on that we do in-house management, or we do first level troubleshooting and all that. Most of the training and certification will come from the manufacturer. Then we can go and work on those devices. … by doing that, you'll be saving a lot of money and also time - the lost time of not - the lost time for a device - for a broken device. So, you can inhouse do it."*

Sam: *"Usually, again for funding reasons, we try and tee in that vendor training with major purchases, get that rolled into the capital costs and then you'll get the opportunity to train couple of people and then you get them to do some internal training within your team. Which is how they learn about what we're implementing. Again, that can be too narrow in terms of the skill set that we need to develop in."*

Andy: "*If we have many uptakes in terms of there's a group, enough numbers of groups, the vendors or manufactures are more than happy to bring all the training gear and set up a training site within one hospital."*

According to Andy, a Biomedical Managers' Group (BMAG) brings together the heads of BME departments in local hub districts, who "*meet up … once a month, and whoever has a manufacturer training established, they will open up who is interested to join. They can send their staff to join*."

There are also service agreements in place with the manufacturers, which enable the training to be run in-house but still be recognised/accredited by the manufacturers. At RPA in relation to the higher, more complex type of medical system, the *"engineers are being tasked to set up a partnership service agreement whereby they allocate some time to bring up the skillset level in-house in the biomedical engineering group, which is accredited by the manufacturer*." In these circumstances, according to Andy, the engineers "*need to achieve a certain level of competency before they are deemed to service their equipment, at different tier levels, we call it. Tier one, tier two*." By contrast, the sub-acute care devices can be managed, maintained and repaired in-house.

One on-the-job training method explored by Malkin and Calman (2014) found that students who completed a nine-week summer program, during which they repaired medical equipment for use in disadvantaged communities, not only taught useful skills but gave students a greater sense of purpose and self-worth. As one student put it:

> *"One day, a nurse in the maternity ward [in Nicaragua] gave us a broken fetal Doppler, her only one, and a box of 'trashed' ones, and we mixed and matched parts until we had three working Dopplers. When we delivered them back to her she gasped and was speechless until she finally said 'por mio?!"… Just the look on her face when she saw those Dopplers made my heart leap"* (Malkin and Calman 2014).

NSW Health may consider implementing a similar program whereby students can gain vital repair skills and understanding of medical equipment while simultaneously reinforcing the humanitarian aspect of health care. Such a program could provide further use for old equipment.

Are there established career pathways or career progression for BMEs in NSW Health?

There are six distinct levels covered by separate awards in NSW Health.

These are as follows:

- Director / Deputy Director (Biomedical Engineer Award or Health Managers (State) Award)
- Biomedical Engineer (Biomedical Engineer Award and Public Hospitals (Professional and Associated Staff) Conditions of Employment (State) Award)
- Senior Technical Officer (Health Employees Technical Award)
- Technical Officer (Health Employees Technical Award)
- Trade Staff (Skilled Trade Awards)
- Administrative Assistants (Administrative Officer Award)

The 37.62 FTE BMEs reported as working in NSW, as discussed earlier, are most likely to be those identified as being covered by a combination of two Enterprise Agreements – ‘Public Hospitals Professional Engineers (Biomedical Engineers) (State) Award 2018’ and ‘Public Hospitals (Professional and Associated Staff) Conditions of Employment (State) Award 2019’. For BMEs, the application of two Awards is necessary because the first acts more as an addendum to the second. There is no clear grading structure in either Award, however a third Award, ‘Health professional and Medical Salaries (State) Award 2018’, sheds some light on this, with Biomedical Engineers included in the salaries table including 6 possible Grades (see Table 1).

The need to reference the grade definitions and salaries from separate Awards makes it difficult to understand the progression options and criteria for BMEs. As discussed below in the section comparing various States, Victorian BMEs have a much clearer Classification Definition section and BME specific level descriptions.

Table 1—Biomedical Engineer, Progression and Salary table.

Classification	Rate from ffppoa 01/07/2018 2.5% $ per annum
Biomedical Engineers	
Grade 1	
1st year of service	65,026
2nd year of service	68,983
3rd year of service	73,739
4th year of service	78,801
5th year of service and thereafter	83,896
Grade 2	
1st year of service	89,099
2nd year of service	91,973
3rd year of service	94,855
4th year of service and thereafter	97,719
Grade 3	
1st year of service	103,169
2nd year of service	106,550
3rd year of service	109,951
4th year of service and thereafter	113,808
Grade 4	
1st year of service	118,874
2nd year of service	122,343
3rd year of service and thereafter	125,783
Grade 5	
1st year of service	130,999
2nd year of service and thereafter	133,461
Grade 6	
1st year of service	135,948
2nd year of service and thereafter	138,461

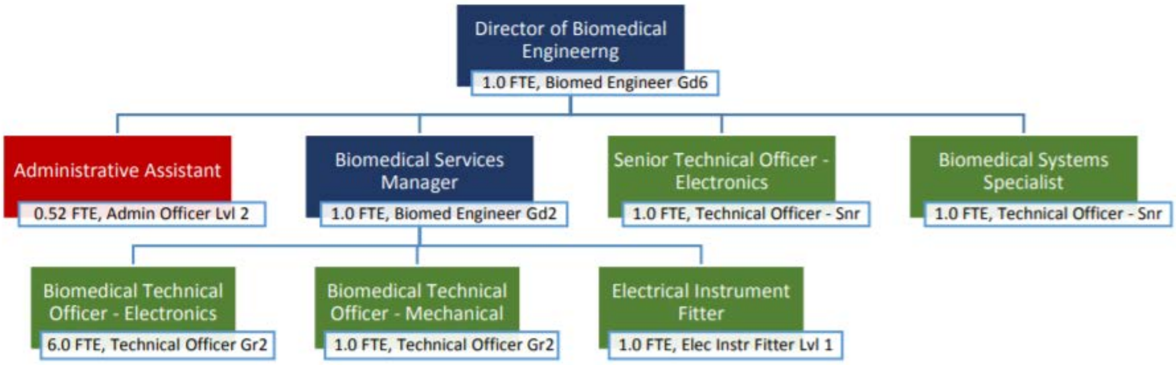
The issues relating to career progression options is not a new one for BMEs working in public health, nor are they isolated to NSW Health. Meese (2016) noted that despite the significant contribution to health and care, the work of BMEs remains largely hidden and undervalued, with their presence and significance often unclear, inadequately recognised and poorly understood by other National Health Service sectors in the UK. Meese (2016) also noted that this state of affairs "*is compounded by the fact that the discipline itself is also fragmented and career paths poorly identified*." Similar problems were identified in Croatia, where access to continued training and recognition of 'grandfathered' skills were identified as issues holding back career progression (Medvedec 2015).

Biomedical Technicians (BMTs) in NSW are covered under the 'Health Employees Technical (State) Award 2019'. The Technical Award is clear and concise, with progression well defined as a function of years of service (see Table 2).

Table 2—Biomedical (Electronic) Technician Progression and Salary Table

Classification	Rate from 01/07/2019 $ per week	Rate from ffppoa 01/07/2019 $ per week
Electronics Technician		
Technician		
1st Year of Service	1,383.44	1,418.03
2nd Year of Service	1,431.62	1,467.41
3rd Year of Service	1,479.89	1,516.90
4th Year of Service	1,573.05	1,612.39
Sole		
1st Year of Service and Thereafter	1,649.83	1,691.08
Senior		
1st Year of Service	1,676.58	1,718.50
2nd Year of Service	1,703.13	1,745.71

The following Organisation chart provides insight into the range of BME positions at St. George & Sutherland Hospitals.



The consensus amongst the interviewees is that career pathways are limited for BMEs in NSW Health. New graduates usually begin at the technical officer level with relatively few distinct levels to climb the ladder vertically. Whether all these levels exist within a LHD/SN depends on its size.

Alex: *"You'll start using that [theoretical knowledge] as a technical officer by looking at devices, working on devices, working in the clinical environment and slowly progress. Not many people - half of them give up halfway through because the progression and the - from that to this is a long route and a long period of time. In the meantime, ... the amount of money you get is also not that very promising. They look for other avenues in the private industry or some people drift away to pure manufacturing or pure research type roles in other places."*

Jamie: *"I don't think there's any clear pathway there like there are in other health professions. It's not really recognised very well."*

Pat: *"If you're a good technician, or if you're a good engineer, hospitals don't provide too much opportunity to grow your engineering skills, should I say. It's more about using what you learn to do things."*

Three interviewees noted in this regard that there were horizontal career opportunities for BMEs to move into across health organisations.

Do training programs in Australia provide the required skills and knowledge for BMEs to work in NSW Health? If not, what additional or different tertiary programs and workplace training should be provided?

The undergraduate programs available to students are believed to be satisfying the technical knowledge and skills needed for electrical and biomedical engineering. However, a number of other skills were identified by the interviewees as opportunities for development in training programs, which would better equip BMEs working in NSW Health. Other skills or knowledge raised as potential additions to training programs included: risk management, leadership, management and procurement alongside improved 'soft skills'. Interviewees also stressed the need for degree programs to be future-looking, so that new graduates would be able to develop skills they will need in five to ten years' time. The major biomedical undergraduate degrees already cover ICT/ system networking as part of the curriculum.

Challenges and opportunities identified by a number of interviewees in relation to skill development beyond scientific and technical knowledge include:

- risk management of devices in NSW Health
- management of the provision of service beyond procurement, including oversight and management of third parties, contractors, and OEMs
- commercial acumen
- teamwork and communication skills
- new technologies such as the augmented and virtual realities.

While not referred to in the literature, the health service interviewees identified critical deficiencies in training programs for employment in NSW Health as including: the lack of training provided to students in relation to the hospital system and working with other health professionals in a clinical environment. Accordingly, they suggested that designing medical devices with patients and the end-use in mind needs to be added to university courses to enable better understanding of psychology and human behaviour and to increase capacity to function appropriately in clinical systems. One interviewee stressed that BME students would benefit from being exposed to how clinical teams operate by actually working in outpatients or on wards for a period. Another explained that working with patients or clinicians during university training occurs in the UK where the experience is greatly valued.

Recruitment and Retention

Are there recruitment and retention challenges for biomedical engineers in NSW Health? What are they?

According to Hine (2016), there should be enough supply of BME graduates to service any demand from NSW Health. While STEM courses are attracting a smaller proportion of overall enrolments than they did in previous decades, BME has witnessed a rise in popularity among engineering graduates, and especially among female engineers (Hine 2016).

In Australia, in absolute terms, the proportion of STEM graduates declined between 2001–2011, from 21.7 per cent of all university graduates to 16.5 per cent (Hine 2016). In addition, the level of primary and high school students participating in and performing well in STEM fields has been decreasing across the nation. Australia's international standardised testing results have been slipping in STEM subjects since the early 2000s. These statistics indicate that while Australia might currently have an educated and experienced workforce in the STEM fields, the pipeline is diminishing.

At an Australasian BME workshop, Dokos (2015) noted that there was possibly an oversupply of graduates for the small Australasian market. The university departments being represented were graduating a total of about 250 BME students annually, with a further 100 at the National University of Singapore and 25 at the Auckland Bioengineering Institute. While NSW Health is competing with private enterprise for graduating talent, there is no dearth of qualified graduates seeking employment every year.

In short, at present there appears to be a demand side issue rather than a supply issue in relation to recruitment of qualified BMEs. However, the total market for BME professionals in the nation is expected to grow in line with the broader biotechnology sector, an industry that increased by 3% between 2007 and 2016, while the global biotechnology industry grew by 10% (Hine 2016).

In Sydney, for example, the leading BME employing companies are ResMed and Cochlear, two Australian-founded multi-national medical device companies, which together employ less than 50 new graduates each year. Australia-wide there are some 500 medical device companies, most of which are small businesses employing only a handful of staff. Such companies typically seek to employ engineers with specialised experience in more traditional disciplines, such as electronics, material science, mechanical or chemical engineering, as opposed to those with a broad biomedical engineering education. With an excess of 250 new BMEs expected to graduate each year across Australia for the foreseeable future, NSW Health should be able to attract and retain qualified BME graduates into Level 1 positions relatively easily, provided these graduates are made aware of employment opportunities in NSW Health.

Those who have engaged with university-based internships or run their own internships noted they have a pool of suitable candidates.

Andy: *"I have more than six years of this internship program established. Every year I have six graduates from my database, so I have more than 30 fresh - an email list which I can reach out."*

The most significant recruitment and retention challenges raised by interviewees from the perspective of attracting candidates centred on salary levels, the routine nature of the work, and the fact that design and innovative work is easier to find in the private sector. Most agreed that entry level pay for new graduates is largely in line with or better than industry. This is not the case for more senior positions in which it is considered quite low. This fact combined with the limited career opportunities to advance, creates a significant retention issue for the health sector.

Andy: *"In fact, we've been overrun with lots of requests coming from undergraduates at times, that we have to shortlist, and we have to refer to other districts ... It's competitive, as I mentioned, and public healthcare, we have higher base entry salary renumeration compared with private sector … For young engineers or young biomedical engineers in public healthcare, the retention is good. The cost, the remuneration is good. Unless they find that it is very monotonous and monotony is, they want some excitement, they want to see the world, they move on. That is for young engineers, our frontline support team is quite stable. They don't really rotate, or the turnaround is not that high, but the more senior role is a bit hard to find. Senior role is basically also probably it's because of the remuneration as compared with private sector. In senior role, you get much higher pay grade in private sector than with public sector."*

Sam: *"The only thing I would add to that in terms of salary at the entry level is probably quite reasonable, in that the majority of places around the state, an entry level technician will get in with an advanced diploma.The pay scale for a technical officer, grade 2, which is typical entry level position, it's - over four years it goes from about 72 to 80, which isn't bad … I suppose if you're at the top end of the director scale there's a sort of ex-super number, where you'd be talking sort of 140 ish.That's the sort of band that they play in. The lack of progression opportunities basically mean technical officers will either move to where there's a senior technical officer position vacant, or they will move somewhere that's half an hour closer each way to their house. They can go there and do pretty much the same job for the same money, and because they're already working in the field and we have got this skill shortage, if you go for the job you're almost certain – highly likely to get that position."*

It can be suggested that an additional recruitment challenge is the lower visibility of NSW Health as an employer of BMEs compared to private industry and competition with other fields, such as medicine.

Taylor: *"Medicine, I mean medicine's very sexy of course and biomedical engineering is not particularly sexy, so engineering itself has got the usual identity crises, same when you think about bioinformatics and everything else. So, I think the identity* *crisis is part of the way the universities still present a very siloed attitude towards their teaching, so everything's very discipline specific and faculty specific."*

The major advantage NSW Health has over industry, particularly for some roles, relates to the BMEs being able to see how their work directly benefits patients. One interviewee commented that she was attracted to working in public healthcare because she "wanted to work closely with clinicians and patients" and did not "want to be stuck in an industry working on some device and never actually seeing the end user or the benefit".

Interviewees also noted the difficulty in finding suitable engineers with the 'right skill set', notably those who can problem solve and troubleshoot; important skills for working in NSW Health. In addition, interviewees identified two inter-related looming issues: turnover associated with the ageing workforce in NSW Health and the availability of suitably trained and qualified people to replace those leaving.

Frankie: *"Aging workforce; it's probably something we haven't talked about. So when I look at, when I look at the workforce, there seems to be a cohort of employees that are really getting very close to that retirement age and I'm always questioning have we equipped our other engineers well enough to now replace those people who have probably been in a management role for a very long time."*

Sam: *"Finding suitably skilled, qualified, trained people with the communication skills required to carry out the role, there's an extreme shortage of them. Both at the director level and at the technical level, across the board. There's a lot of people I've interviewed who've gone, there's no way I could have them work here; will turn up a month later working for a vendor. It's a very narrow set of things they need to look after and the instruction manual – if this problem is this, then you do this. Whereas in my site alone there's probably 1100 different equipment types we look after, so you're never going to be trained on even 10 per cent of it. So you need really good generic troubleshooting skills and an understanding of what the device does, what's happening with the patient in order to get to the bottom of that."*

Adrian: *"When managers go out to find clinical engineers to fill gaps, vacancies there are very few people out there that have the knowledge and skills. There is a need there to get the appropriate training, on both sides. Biomedical engineering departments are desperate for good engineers, and on the other side they're not taking the university graduates because they're not matching up with what the role requires. … "That's the big problem. If you could solve this problem. The problem is they go on this career path into degree, come out of a degree."*

A major retention issue raised by several interviewees related to the lack of adequate career pathways in biomedical engineering in the health sector.

Charlie referred to one senior BME in the hospital system who had 15 years' experience but that there was "*nowhere for him to go*" other than up to a corporate executive position "*because there's no discipline related career path.*" Similarly, Sam, a BME in the health sector, commented that the career pathway was an "*extremely limited one*" and Jamie argued that there was no clear career pathway as was the case in other health professions, which affects the new BME entrants to the health sector.

Are there recruitment and retention challenges for biomedical technicians/support workforces in NSW Health?

One interviewee stressed that technicians are more stable employees and retention is less of an issue with this classification, partly because there are fewer competing job opportunities in private industry.

Alex: *"A lot of technicians with the advanced diplomas in electronics, they tend to settle down a bit more than the engineering people … They have a more stable job and the growth is not that much compared to - engineers see a lot of growth in other aspects of biomedical engineering and they can diversify to any branch, including IT. Technicians have a limited scope. Even they are evolving. They are also the smartest people."*

However, the types of candidates applying for the technician role is changing, with more highly qualified degree candidates seeking to fill these lower level roles. Although not specifically addressed in the literature, interviewees noted that they were seeing fewer applicants with diplomas or certificates. Several factors are contributing to this development.

One relates to pay rates. Andy noted that BMETs in health can earn *"$10,000 more than an engineer's job in the private sector*."

Another relates to the increasing hospital demand for equipment, such as for cardiac monitoring, respiratory therapy and other technologies, which have support requirements, and which therefore increase the need for the technician workforce to grow at least in the immediate term.

A final factor highlighted was the impact of competition from industry on retention, which Morgan described as "*probably one of the biggest threats*" in regard to the engineering graduates entering as technicians because once they obtain the three or four years of training in clinical engineering and an understanding of "*the clinical environment in the hospital … the commercial organisations would come and poach them away with a higher salary, without having to train them because we did it for them*."

Are advertised positions for both biomedical engineers and technicians filled?

Regarding entry level positions, those interviewees who have knowledge of recruitment within NSW Health referred to the difficulty of attracting a decent number of applications for experienced candidates particularly for more senior roles. Some interviewees referred to issues relating to overseas applicants. Sam noted that if he advertised a technical officer position he would probably receive "*somewhere between 20 and 40 applicants*" of which he would interview up to seven and, while a lot of them are highly qualified overseas applicants, they tend to lack work experience in Australia or their qualifications have not been recognised by Engineers

Australia. Sam commented that *“it’s really difficult trying to work out which of the qualifications from some countries are legitimate and which are not.*”

Future Challenges

What advances in service delivery and/or technology will require additional or different BME support?

Technical innovations are set to revolutionise healthcare in the coming decades. The healthcare IT sector is experiencing exceptional growth with the ongoing revolution in the broad areas of information, electronics, communications, computation, and internet technology bringing tremendous opportunities for the provision of healthcare services (Wheeler 2014). Big data for instance, will allow doctors to undertake predictive modelling and trending to pinpoint for example, outbreaks of disease linked to environmental conditions. The development of telehealth and smart phone apps, which access body worn measurement systems are also set to transform the way illnesses like diabetes and heart disease are controlled and monitored. Surgical robotic manipulators will become more prevalent allowing surgeons to navigate deep inside the body, avoiding the risks and complications of traditional open surgery. Such innovations will allow even complex interventions to be treated as day cases. All these technologies are set to improve patient care and also to help ease the burden on increasingly overworked clinical staff. BMEs are needed to properly exploit these technologies (Finlay et al. 2014, Meese 2016b, Meese 2017).

In 2015, the US Deloitte Medical Technology Division envisioned four areas of change that are likely to shape the medical technology landscape (Snyder 2015):

- *“Shift from acute to preventive care, specialists to self-care, and hospital to home care. More services will likely take place in non-traditional health care settings. Consumers with remote access to data through smart devices can manage their own care conditions*
- *Shift from monitoring single biometric indicators to multiple indicators, processed through artificial intelligence. This can provide true health insights*
- *Shift from intuitive approaches based on empirical evidence for typical patients to precision-based health care rooted in the individual patient’s characteristics. This can allow physicians to harness information from intelligent algorithms to inform treatment decisions*
- *Shift from specialized silos of medical knowledge to more centralized and accessible knowledge centres. This can allow clinicians to provide sophisticated care without necessarily having specialized training.”*

Historically, most hospital based biomedical engineers have been originally assigned to either research units or operational duties of managing, planning, maintaining, and training on use of medical devices. However, there are significant new 'grey’ areas in the design and management of future healthcare systems that will require a more comprehensive skill set that extends beyond the traditional ones. The WHO (2017) report identifies four areas that are of increasing importance in the health sector due to technological change and the competencies and skills that BMEs will need to develop to deliver on these:

*“**Strategic services**: These are concerned with issues three to five years in the future, including standards development, regulatory policies, device design, Research and Development alliances, academic partnerships, market development, professional scope of practice, professional training, credentialing and continuing education. A long-term strategic overview is needed in order to determine how best to divide up the new responsibilities between IT, biomedical, clinical and other health facility staff. The strategic clinical services that biomedical engineers provide could include the capacity to design and evaluate clinical research, design and evaluate new clinical practices, and consult with clinicians and all system life cycle stakeholders to develop coherent models of care. New operational skills will be needed to troubleshoot complex networked and virtualized environments of care, to manage the constant updating and upgrading of medical devices, and to provide ongoing feedback to organisational planners regarding the performance of the existing device infrastructure.”*

*“**Convergence**: Devices and information systems will continue to converge, making separation of one from the other harder and harder. Although skill specialisation may often be valued, cross-training and collaborative team problem solving may be equally important. New skills will be needed by these BME managers, because the stakeholders they work with span such a large number of disciplines and professions. Their skills should be situationally and contextually appropriate, flexible and adaptable for communications between learning teams, coaches, mentors, leaders, partners, and providers.”*

*“**IT systems alignment and integration**: Biomedical engineers, clinical engineers and biomedical equipment technicians will need a better understanding of core IT infrastructure components and skills, including topics like software, networks, databases, security management, change management, user interface design and configuration, decision support systems and wireless communication systems. Many, and perhaps most, devices will have one or more of these IT components embedded, and the selection, safe deployment, and ongoing maintenance and repair will require competent IT troubleshooting with IT peers and coordinated repair processes. Further, because most devices will likely be interconnected with one or more electronic medical record systems (EMR or EHR) clinical technology management staff will likely need EMR/EHR support skills in order to perform point-to-point or device-to device or device-to-system safety and performance validation and verification. Such skills are all the more important because and since those electronic medical record systems may themselves introduce significant patient safety risks and challenges.”*

*“**The ITIL framework**: The Information Technology Infrastructure Library (ITIL) provides an indispensable model for aligning mission-critical services, business processes, data models and activities between IT and biomedical systems. The criticality of aligning these dynamic service functions cannot be overstated, as IT and biomedical systems become more interoperable and interdependent. Biomedical engineers will benefit from receiving formal training in the ITIL model*

and participating in ongoing efforts to architect the organisational capabilities needed to enable IT and biomedical systems to interact and co-evolve in a rational, mutually supportive fashion. The ITIL service life cycle identifies essential business processes that IT and biomedical functions must align in a constant and systematic fashion."

The transition of clinical environments from standalone medical devices to integrated clinical systems fosters an integration of tasks between CED staff and information technology departments, medical device integration, which is becoming a top priority for healthcare institutions (McAlpine and Vankampen 2011).

The interviewees were very aware of these emerging technological developments and the opportunities these advances create for BMEs. Several discussed how these advances will alter the work of NSW Health. As will be discussed further below, in relation to ICT and the introduction and management of medical devices using Artificial Intelligence (AI), Internet of Things (IoT), and 3D printing that will change the patient experience, BMEs can contribute to the growing need for more individualised data, and the growth in community and home based care.

A number of interviewees commented that new technologies, AI and the acquisition of data will require efficient support systems but at the same time increase opportunities for remote health and telehealth. Remote monitoring devices, for example, can increase capacity for patients to be served in private homes and retirement and community centres which, in turn, "*helps to keep people who don't need to be in hospital out of hospital,*" as Sam put it, thereby freeing up hospital resources in future.

Rather than seeing BMEs as being negatively impacted by these changing technologies, the interviewees see BMEs as the catalysts for creating change in healthcare systems. Indeed, they argued that new technologies and automation increase the need for BMEs in NSW Health.

Taylor: *"I think the disruption will come from the biomedical engineers that create the solutions. So, I would have thought that the biomedical engineers play an absolutely critical role."*

Andy: *"Subacute has moved away from manual into automation. Transactional process. They are automated. So, for biomed, we see that we are moving into a system management. We are the one that sits in the background to manage the automation. … It's an opportunity."*

Alex: *"The fact that we manage medical devices more than anything else, it says that they need to be somebody doing that job. No matter how much technology you put in, you still need us … biomedical, technology – no matter how much it changes, you need a physical person for that physical device that's sitting in the physical space. There's no way you can replace".*

Drew: *"I think [AI] will be a great opportunity. As opposed to a disruptor, it will be a great opportunity within the profession … a potential area of expansion and growth for the profession. A lot of that will be invested in the vendors and the manufacturers in around building and clinical decision support using AI and those sorts of things, but ultimately that will flow through to local activities, research and application of* *the principle. So, it won't turn the profession on its head. It will change it, and should be embraced, and should provide opportunity."*

These technological changes impact how BMEs work and their key duties and functions taking them well beyond maintenance of devices and management of OEM contracts. As a result, the importance of different skills and competencies will increase, including IT skills, multidisciplinary skills, management skills, trouble shooting skills, all of which will require further training not only in the new emerging technologies but also in the 'soft skills' mentioned earlier. Such skills will be essential for the shift of patient care from the hospital to the home and the community. Given the expansion of AI, training will also be needed in mechatronics and networked systems.

Interviewees identified various soft skills as necessary for BMEs. For Jamie these included: team working skills particularly working with people from different disciplines, good problem solving skills, thinking skills and capacity to communicate with surgeons, physiotherapists and patients. For Frankie, these included: the capacity to "*think more logically through a problem, so they're problem solving ability and part of that problem solving process should be an economic evaluation on whether I do A or B, it shouldn't just be a technical decision that we are making along the way."*

Concerns about the need for soft skills led a few interviewees to raise issues about BME training. For Charlie, university engineering courses need to:

Charlie: "*give people the education required that they can actually function appropriately in the clinical system and understand what's going on and communicate in the clinical system, and they need to be exposed to how clinical teams operate by actually working in outpatients or on wards for a period*."

Similarly, Frankie commented:

Frankie: "*So, understanding the clinical environment, the clinical application of the equipment and the engineering principles, then the hands-on skills of doing the electrical safety testing, doing the performance verification, the basic maintenance and servicing, and then thinking through troubleshooting … I don't think even we approach troubleshooting techniques very well. There's nothing that really trains you how to do that."*

What are the other drivers that may influence demand for biomedical engineers in NSW Health?

Aging Population

The sources highlight several broad trends driving future growth across the sector that will increase the demands on health services and the need for BMEs and BME solutions to meet the increased demands.

First, the ageing Australian population and the earlier onset of chronic diseases are expected to increase domestic demand for healthcare in the future (Deloitte Access Economics 2015). In

2016–17, people aged 65 and over accounted for 2.8 million same-day hospitalisations (42% of the total 6.6 million) and 1.8 million overnight hospitalisations (41% of the total 4.4 million) (AIHW 2018).

In 2017, 15% of Australians (3.8 million) were aged 65 and over; this proportion is projected to grow steadily over the coming decades (AIHW 2018). By 2057, it is projected there will be 8.8 million older people in Australia (22% of the population) and by 2097, 12.8 million people (25%) will be aged 65 and over (See Figure 4). Growth in the proportion of older Australians is partly due to increasing life expectancy: in 2014–16, a 65-year-old man could expect to live another 20 years and a 65-year-old woman another 22 years, that is, 7 years longer for both sexes than in the mid-1960s (AIHW 2018).

These numbers are further supported by the Australian Bureau of Statistics (ABS), which has projected the proportion of Australians over the age of 65 to increase from 15% in 2017 to between 21% and 23% in 2066, with NSW matching these exactly in a sub analysis (ABS 2018b). Utilising the median population projection model from the ABS, in 2066 Australia will have a population of 42.6 million. If hospitalisations continue at current rates, 11.4 million same-day admissions per year can be expected, assuming the over 65 age demographic continues to account for 42%, this equates to 4.8 million admissions or a 71.4% increase over five decades. Such increasing demand will invariably place strain on the health system and create demand for increased efficiency.

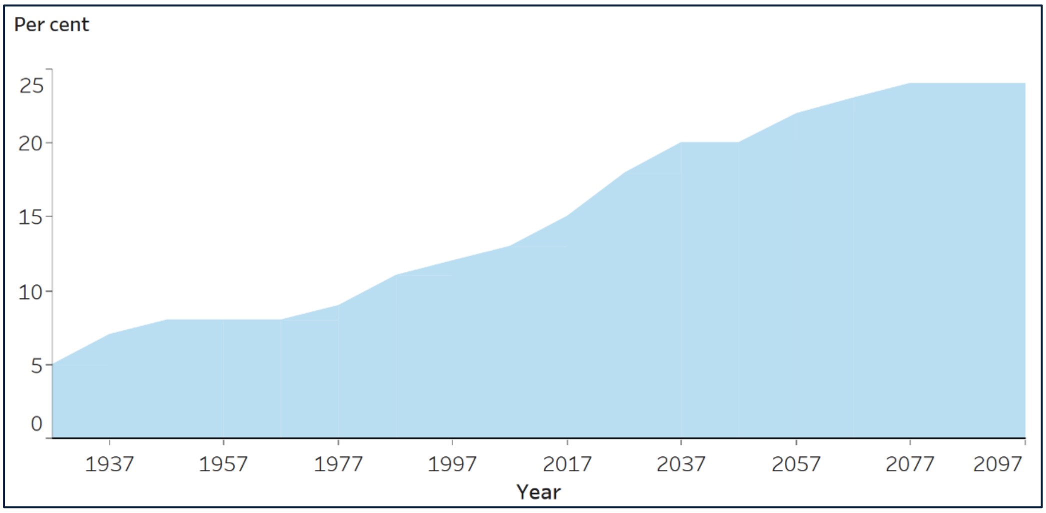


Figure 4—Projected Proportion of the Australian population aged 65 and over (AIHW 2018).

Medical Tourism

Additional demand is expected to come as the large populations in countries across the Asia-Pacific region become wealthier, older and demand more healthcare. Export opportunities for Australian healthcare services and devices are expected to increase (Deloitte Access Economics 2015). Furthermore, an increase in demands on local health services from medical tourism is forecast by 'Strategy&'—a part of the Price Waterhouse Coopers network—to both increase demand and help to drive economic growth into the future (Bartlett 2016).

Personalised Care

Demand on health services is also increasing as a result of the public demand for more personalised care. Personalised care, as defined by Teng et al. (2013), is "*the customization, personalization and tailoring of care for each individual patient, but for which no uniform definition exists*." This personalisation can come in the form of "*targeted prevention and therapeutics based on molecular characteristics*" or "*targeted evidence-based care paths that incorporate aspects of personalized healthcare*" (Teng 2013). Alternatively, personalisation may come in the form of patient demand for a certain type or brand of medical device or treatment pathway.

Several interviewees discussed the changing focus of healthcare towards greater personalised, patient-centred care and remote/ community based care, which is driving the need and demand for the new technologies discussed previously. Interviewees noted that patients increasingly want to have access to their health data and to be able to track their own health.

It was suggested that BMEs will play a key role in guiding and assisting clinicians to respond to the use of new medical technologies and devices that can be used to improve patient care, as follows:

- the management of mandated patient health records
- increased community access to personalised health data that can enhance individual understanding of health needs creating greater demand from members of the community for better tracking and monitoring of their personal health
- use of new personally designed health related interfaces by doctors and patients.

As these myriad of pressures mount on front-line health services, technology and the BMEs who develop, procure and maintain such technology, have the potential to not only ease the burden on the health sector but also significantly cut costs (Meese 2017). As overall demand grows along with the shift towards more personalised healthcare, BMEs can assist in the overall efficiency gains and the provision of direct patient services through the application of new technologies and the manufacture of patient-specific devices. In such an environment, there is a need for healthcare providers to develop executive roles to oversee these services and to develop new roles in response to changing demands and developments (Meese 2016a).

Biomedical Engineering workforce in other jurisdictions and countries

Victoria and Queensland

The last time a comprehensive survey of the medical physicists and the BME workforce was completed by the Australasian College of Physical Scientists and Engineers in Medicine (ACPSEM) was in 2012 with results reported in 2013. At that time NSW was a long way behind the Australian Capital Territory (ACT), South Australia (SA), Western Australia (WA) and Victoria, (Vic) in terms of per capita BME employment (see Figure 5).

In 2012, Victoria had the largest BME workforce of any state in Australia, with an Equivalent Full-Time (EFT) workforce of 76.3 BMEs. This equates to 13.6 BMEs per million citizens in the State at the time. When compared to NSW with only 19.7 EFT positions or 2.1 per million citizens, Victoria had 5 times the number of BMEs per capita in 2012.

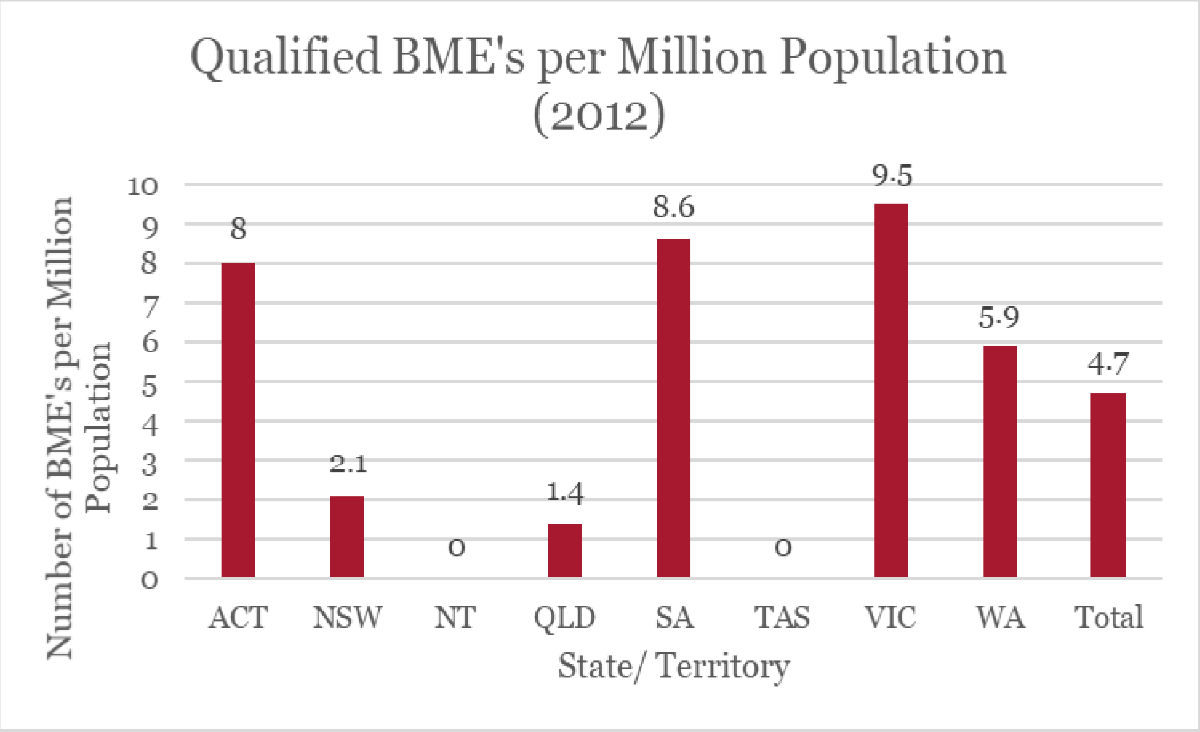


Figure 5—Number of Qualified BME's per Million Population in Australian States and Territories. Data sourced from (Round 2013)

Of the three most populated states in Australia, Queensland had the least number of BMEs per capita (1.4 per million) and as per Figure 6, the highest healthcare costs per capita.

In 2012–13 Victoria became the most cost-efficient State in terms of health expenditure and has held this status since. It cannot be inferred from this that a greater number of BMEs equates to lower cost overall as there are multiple variables at play. However, Victoria having almost five times the number of BMEs is not resulting in an increase in health costs per capita, suggesting that the BMEs in Victoria are providing value relative to the costs of their wages.

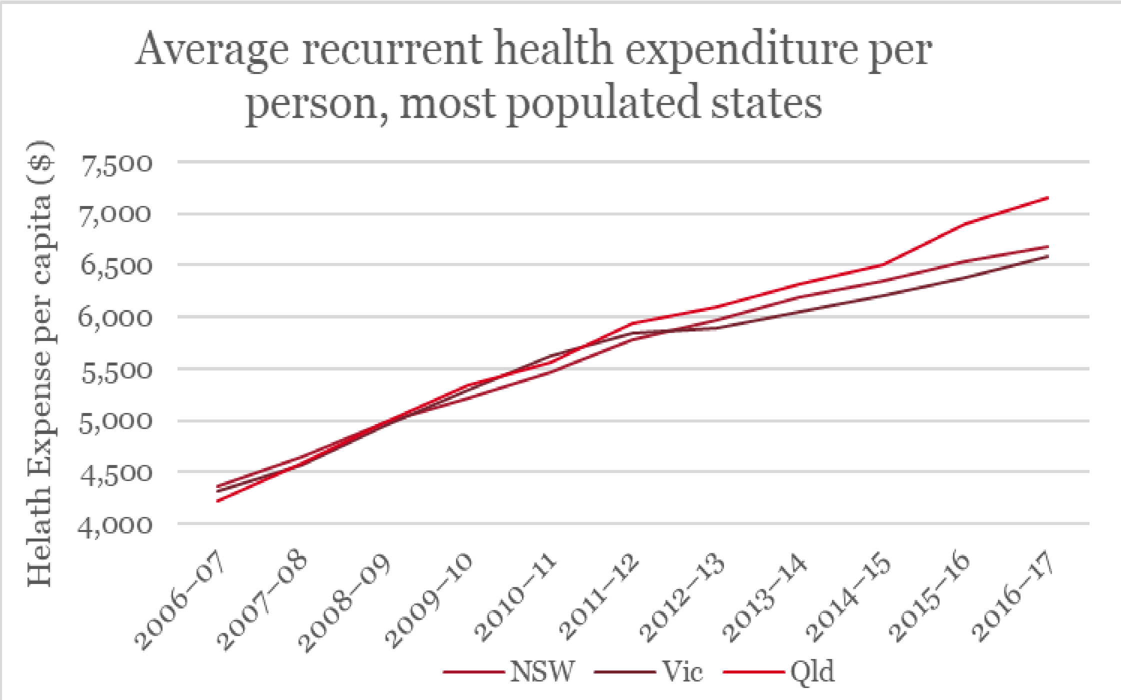


Figure 6—Average recurrent health expenditure, per person in the Three most Populated Australian States. Data from Table 2.11 of (Health and Welfare 2018).

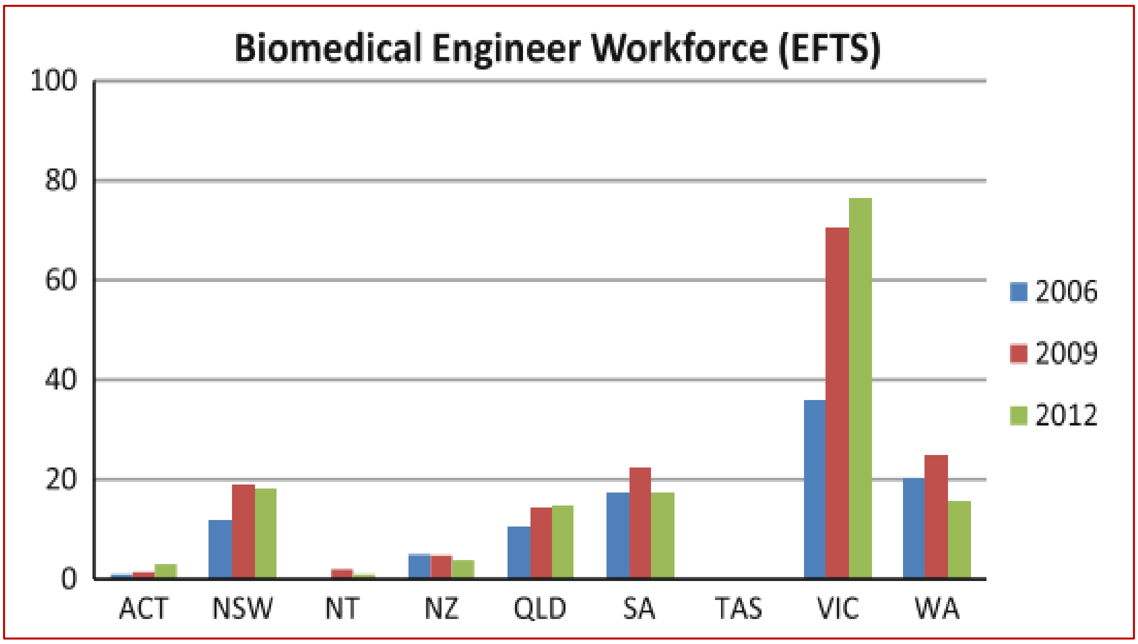


Figure 7—Australian Biomedical Engineer Workforce – Equivalent Full Time Staff, 2006-2012 (Round 2013).

In 2012, NSW Health paid higher salaries than its Victorian counterpart across the different grades of experience up to 20 years, as shown in Figure 8. Also noteworthy in Figure 8, however, is that at this time NSW was not employing BMEs with 3 or less years of experience.

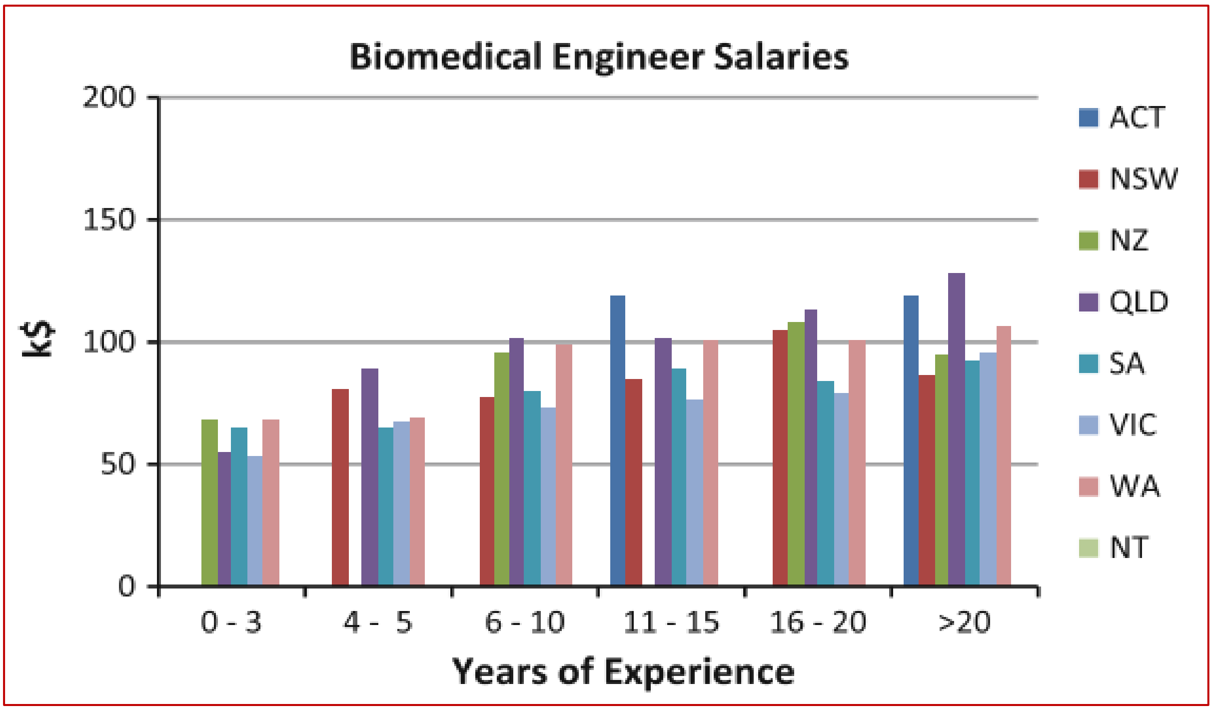


Figure 8—Australian and NZ Biomedical Engineer Salaries, Grouped by State and Experience (Round 2013).

Comparison of NSW, Victoria and Queensland Enterprise Agreements

New South Wales, Victoria and Queensland have current Enterprise Bargaining Agreements or Awards in place that cover Biomedical Engineers and Biomedical Technicians as negotiated by their respective Industrial Associations.

As discussed earlier, NSW BMEs are covered by a combination of Enterprise Agreements: ‘Public Hospitals Professional Engineers (Biomedical Engineers) (State) Award 2018’, ‘Public Hospitals (Professional and Associated Staff) Conditions of Employment (State) Award 2019’ and ‘Health Professional and Medical Salaries (State) Award 2018’, which stipulate the respective salaries for the various levels. BMTs in NSW are covered under the ‘Health Employees Technical (State) Award 2019’.

Victoria has specific coverage for BMEs. The Victorian Public Health Sector (Biomedical Engineers) Enterprise Agreement 2018–2022 clearly elaborates Classification Definitions into 5 classes and includes a progression roadmap. BMTs do not appear to be covered under the BME Agreement, nor are they explicitly covered elsewhere. The closest Agreement seems to be the Allied Health Professionals (Victorian Public Health Sector) Single Interest Enterprise Agreement 2016–2020, which refers to numerous types of technicians but does not explicity refer to Electrical Technician or device maintenance position.

In Queensland, both BMEs and BMTs are covered under the General Employees Award (‘Hospital and Health Service General Employees (Queensland Health) Award – State 2015). BMEs are classified as part of the Professional Officer stream and BMTs are covered under the Technical Officer stream. Both have 6 available levels of classification or career progression.

A cross analysis of the State Agreements found that the overall entitlements and Awards are broadly similar. However, the Victorian agreement provides better clarity around the Classification Definitions and career progression for BMEs. The Victorian Agreement has 5 *“Classes*” for BMEs, explicitly laid out in their Agreement. The Queensland and NSW Awards cover more than one profession resulting in complexity and the potential for confusion. Further research, enabling an in-depth comparison and the potential for further refinement of the NSW Awards may be beneficial.

Canada and the United States (US)

BME programs in Canada and the US have achieved maturity and are advancing the field rapidly, producing practitioners who work in academia, industry and in the health-care professions as academics, engineers, physicians and other professionals with a focus on medical device design and delivery of health care.

In North America, very few graduates of BME undergraduate programs work in industry immediately after obtaining their degrees unless they have had some internship or co-op experience. For some time, industry has been insisting on a Master degree in BME as the entry-level degree. A few BME undergraduates, upon receiving their degrees, work in hospitals or shared-service organisations, but they often lack experience in critical clinical environments and it has been argued that they need additional training to become effective (WHO 2017).

In the US, there are 97 accredited BME undergraduate programs, but no undergraduate programs offering clinical engineering degrees. There are no Master of Science (MSc) clinical engineering degree programs, although the University of Connecticut offers an MSc in BME with a substantial clinical engineering internship component. In the US, the military provides its own accredited training through the Biomedical Equipment Maintenance Technician Training Program of the Defence Health Agency (WHO 2017).

In Canada, there are 36 universities offering BME degrees, but only two offering MSc programs in clinical engineering (WHO 2017). The gap between technical talent supply and demand in British Columbia was the subject of a 2016 Report by the British Columbia Technology Industry Association, which forecasted that under current conditions, only 16,500 workers will be available to fill 47,000 technology-related jobs by 2021. As a result of these findings the Government of British Columbia committed funds for the creation of 624 spaces in undergraduate engineering and computer science programs at the University of British Columbia (UBC) with 355 seats dedicated to Biomedical Engineering. This prompted the formation of the School of Biomedical Engineering at UBC in 2018—the first dedicated BME School in western Canada (Engineering 2018).

In the US, accreditation of engineering programs is performed by the Accreditation Board for Engineering and Technology (ABET). Today ABET is a not-for-profit, non-governmental accrediting agency for programs in applied science, computing, engineering and engineering technology recognised as an accreditor by the Council for Higher Education Accreditation. By receiving ABET accreditation, college and university programs are assured of meeting the quality standards of the relevant profession for which the program prepares graduates. Programs, not institutions, are accredited and accreditation is voluntary. It provides specialised accreditation for post-secondary programs within degree granting institutions already recognised by national or regional institutional accreditation agencies and national education authorities worldwide. In 2017, approximately 3,600 programs across 700 colleges and universities in 29 countries had received ABET accreditation. Each year around 85,000 students graduate from ABET-accredited programs (Phillips et al. 2000, Walsh and Cain 2017).

The evolution of clinical engineering certification in Canada started in 1980 with the development of a Canadian Board of Examiners, which used both written and oral examination methods to determine candidates' eligibility for certification. In the 21st century, the activities of the Canadian Board have been aligned with its US counterpart, to the extent possible, to try to ensure the sustainability of the Canadian Board. The main differences are the need to examine Canadian candidates on codes, standards and regulations that are Canada-specific, and the requirement in each Canadian province or territory for licensure as a professional engineer if the title engineer is to be used. The Canadian and US Boards are both accountable to the Healthcare Technology Certification Commission (Easty 2015).

Pat and Frankie both expressed the view that Australia is falling behind the US in terms of both training and translating BME skills and innovations into useful products and services. Pat extolled the virtues of "*hospitals becoming translational research centres*" going on to say that while there are "*models around the world of this stuff, but it is hard. It's hard, it takes multiple generations of government to implement. The Australian Government, their timing is so short.*" This model works in Pat's opinion when:

> *"Universities have a close link to a hospital that links in with the industry sector, it's a huge network there in academics. That way, they can, I guess, bring in or retain these talents who want to innovate and use hospital as a place to continue to develop and innovate. But this will require complete cultural change."*

Frankie concurred in the view that Australia is behind:

Frankie: "*Having worked for a multinational for quite a few years I'd say in terms of the adoption of technology, yes we are behind as a country and the US certainly have adopted more innovative technologies than we have and for whatever reason they are incentivised to do that, possibly because of the way the healthcare system in funded. So yes I think we are lagging."*

United Kingdom (UK)

Biomedical engineers (more consistently in the UK called Clinical Engineers) work throughout the National Health Service (NHS), providing a crucial role in the development, selection, use, maintenance and decommissioning of technologies. However, unlike many other NHS professions, there is little uniform recognition of the BME.

In England, hospitals are grouped into 162 Acute Trusts, of which 100 have Foundation Trust status. Elsewhere in the UK, hospitals are grouped and managed by Health Boards or Trusts, with 14 in Scotland, eight in Wales and five in Northern Ireland. In total these trusts and boards are responsible for 353 hospitals (Directory ND).

In the NHS, BMEs/CEs are often assigned to different departments, operate at different levels of authority and have varying input into critical decision-making, depending on which Trust they are employed by. This inconsistency not only undermines the work of engineers, but hampers connectivity between Trusts on the development, procurement, maintenance, and sharing of medical equipment (Meese 2017).

Between August 2018 and August 2019, the NHS served 21.0 million "*finished consultant episodes*", 12.2 million (58.1%) which included at least one procedure or intervention. Additionally, there were 17.3 million "*finished admissions episodes*" of which 6.5 million were emergency admissions (NHS Digital, 2019a). In order to service these large numbers of patients, the NHS employed more than 1.7 million in 2012—making it the 5th largest employer in the world in at that time (Telegraph 2012).

The best estimate for the number of Clinical Engineers (CE) in the NHS in 2019 is 3049, or roughly 45 per million population. According to a NHS Digital statistics (seeTable 3) released on the NHS Workforce, there are 2,138 employed under the 'scientific, therapeutic and technical staff' subset, with a further 911 classified under 'Support to Scientific, Therapeutic & Technical staff (ST&T staff)'. These numbers are exclusive to England only because Wales and Scotland were not included in the data released. The UK Office for National Statistics estimated the population in England to be 55.98 million in 2018 (Statistics 2019), which equates to 55.16 Clinical Engineers per million population, a full five times greater than Victoria—Australia's most serviced state. However, this may not be a fair comparison given the known issues with accuracy of BME/ CE workforce estimations in Australian States. According to Finlay et al. (2014), the NHS is not only one of the largest publicly funded health services, but "*also one of the most efficient and comprehensive*." Given the problems relating to data on BMEs in Australia's health sector and the outdated information provided by the Australasian College of Physical Scientists and Engineers in Medicine 2009 and 2012 survey data for public health in Australia and New Zealand (Round 2013), there are no percentages that can be compared to the English data.

Table 3—Clinical Engineers in NHS - England only (NHS Digital 2019b)

Sum of Total FTE / Staff Group 1 / Staff Group / Care / Level	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19
017_Scientific, therapeutic & technical staff	**2,152**	**2,155**	**2,160**	**2,157**	**2,162**	**2,157**	**2,160**	**2,155**	**2,131**	**2,138**
019_Healthcare scientists	**2,152**	**2,155**	**2,160**	**2,157**	**2,162**	**2,157**	**2,160**	**2,155**	**2,131**	**2,138**
009_Clinical Engineering	2,152	2,155	2,160	2,157	2,162	2,157	2,159	2,154	2,130	2,137
022_Rehabilitation Engineering	0	0	0	0	0	0	1	1	1	1
032_Support to ST&T staff	**878**	**876**	**877**	**881**	**883**	**890**	**909**	**906**	**904**	**911**
034_Support to healthcare scientists	**878**	**876**	**877**	**881**	**883**	**890**	**909**	**906**	**904**	**911**
009_Clinical Engineering	878	876	877	881	883	890	909	906	904	911
022_Rehabilitation Engineering	0	0	0	0	0	0	0	0	0	0

The presence and significance of Biomedical Engineering within NHS hospitals is often unclear, inadequately recognised and poorly understood. This is in part due to the fact that in the past there was a lack of a single recognised title: Biomedical Engineering was variously labelled as clinical engineering, electrical and biomechanical engineering and rehabilitation engineering. However, since 2014 there has been a standardised use of the title 'Clinical Engineering' (NHS Digital 2019b). Staff may be managed within a medical physics or CE department, within an estates and facilities department, or even reporting directly into clinical services such as renal dialysis services or rehabilitation and enablement services. Specifically, the distinction between science and engineering is not represented well in NHS structures, with engineering often listed as a subset of science (Finlay et al. 2014).

Regardless of the title they are known by, BMEs in the NHS contribute to a wide range of clinical services and provide Trust-wide support. They are often responsible for the entire medical device life cycle from specification to disposal, as well as the design and development of novel and customised devices and delivering expert services directly to patients. Often they provide organisation-level support to clinical and financial governance of medical equipment, including analysing and reporting on incidents involving medical devices (Finlay et al. 2014).

One area in which the UK is doing better than any Australian State is in increasing public awareness around the role of and employment pathway to the Clinical Engineering (CE) workforce. This includes easily accessed information for prospective BME/CE students that helps them understand what the role entails and the necessary training they need. The landing page (see Figure 9) for the UK National Careers webpage on CE has a clear and concise definition of the role, expected salary and work schedule. The webpage also explains how an individual can become a CE via three separate routes: University, Apprenticeship or a tailored NHS Practitioner Training Programme. The CE job-profile page goes further into career opportunities, career progression and what the day-to-day role entails (Service ND).

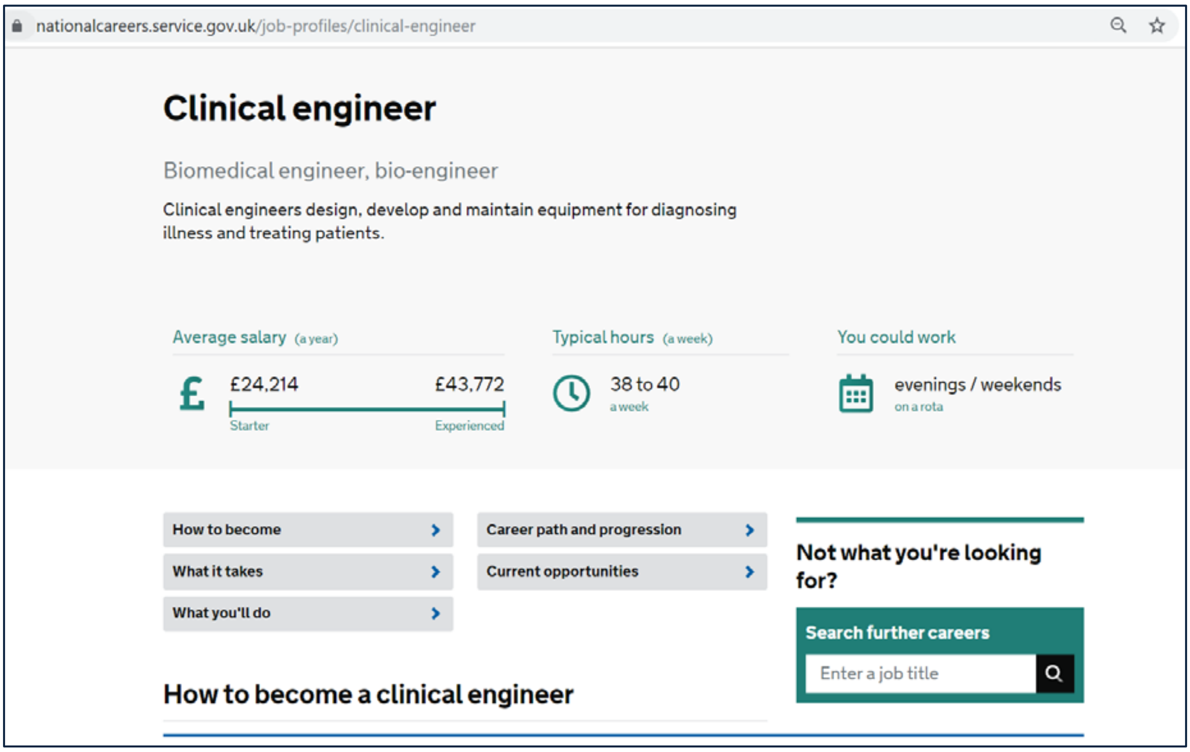


Figure 9—The Clinical Engineer job-profile page on the National Careers Website (Service ND).

The three pathways to becoming a CE not only provide clarity, but also a varied entry into the profession. The webpage notes that following University studies prospective CEs can elect to enrol in the NHS Scientist Training Programme (STP). This program is a three-year postgraduate Master Degree that participants complete while being fully employed. Competition is high for places in this course and applicants are advised to try and find relevant experience in the NHS prior to applying via volunteering to gain patient contact hours.

STP Trainees are employed by a NHS Trust for the duration of the program and spend time in a range of settings, before specialising in the last two years of the program.

The aim of the STP is to produce graduates who will possess the essential knowledge, skills, experience and attributes required of a newly qualified Clinical Scientist in the NHS. They are expected to be competent enough to undertake complex scientific and clinical roles, defining and choosing investigative and clinical options, making key judgements about complex facts and clinical situations within a quality assurance framework. Many will work directly with patients and they will all have an impact on patient care and outcomes. They will be involved, often in lead roles, in innovation and improvement, research and development and/or education and training.

A program such as this may prove to be very beneficial for NSW Health to consider as a pathway to attracting new talent into an organised framework that guarantees to produce competent BMEs and CEs who are ready to work in the public health sector.

Jamie provided further insights into the UK post graduate training and induction programs compared to what is on offer in Australia as follows:

Jamie: *"So, part of the training is once you've finished it you then get accredited by the Health and Care Professions Council, so that means you're safe to work with patients and things. There doesn't seem to be anything like that in Australia, so I don't have to be accredited or registered anywhere in Australia."*

Jamie also explained that the NHS has a more clinical/patient focused specific training program, which she thinks is missing in Australia where students do not get very much experience working with patients, surgeons or other health professionals during their degree courses.

In Jamie's view "*there's definitely more of a career pathway and standardised scheme in the NHS than there is in NSW Health*." As Adrian, who has extensive experience with the UK system, commented:

Adrian: *"The training program that I'm actually running here in Australia now has been developed into an apprenticeship in the UK. So, it's a two-year apprenticeship for clinical technologists which is their equivalent of the clinical engineer, biomedical engineer. … at Kings College Hospital, Kings College University … used to have a clinical - biomedical engineer training scheme as part of the hospital. … You'd have lots of graduates coming out of university without the practical skills and not getting jobs, and when you went to get a clinical technologist, there were very few there that had the right knowledge and skills to come in and work straightaway in the workshop. So, when I was there and when I was a manager, I was taking on work experience students three months at a time. … It came to a point where we had lots of work experience people getting jobs in other hospitals … They've got 12 apprentices going through at Kings College Hospital. So, Kings College Hospital are now not just a biomedical engineering training centre. It's also a clinical technologist training centre ... We're a bit behind, probably I would say 5 or 10 years behind the UK in that way."*

Conclusion

This Study was designed to address two key questions: (i) what is the current state of the biomedical engineering workforce in the NSW Health, and (ii) what are the challenges in maintaining that workforce?

The literature on the BME workforce generally and in health specifically, is limited as is the data on the numbers working in health. This state of affairs has resulted in critical gaps in knowledge. These gaps are compounded by definitional confusion surrounding the BME workforce employed in health services generally and in NSW Health specifically, as this relates to (i) the fragmented nature of the discipline; (ii) use of the term Clinical Engineering as a sub-speciality of biomedical engineering in health services; and (iii) the absence of a registration/certification system for BMEs/CEs employed in health services in NSW.

Generally, BMEs/CEs manage medical devices in healthcare facilities. Whereas by some definitions, biomedical engineering is practised primarily in academic institutions, research laboratories or design and manufacturing in the private sector, it appears that ‘Clinical Engineering’ is the preferred title in different countries to label the work undertaken in hospitals and other health environments where medical device technologies are used. BMEs take care of medical devices throughout their life cycle within health-care facilities, managing not only medical equipment, but also implantable medical devices, in order to safeguard patients’ lives. BMEs may also work with clinicians, nurses and other professionals across different levels of health-care facilities to ensure the best and safe use of medical devices.

BME/CE is a rapidly changing profession as a result of new technologies and new models of health care. These developments are blurring the line between engineers and IT in hospital settings and between BMEs and BMETs.

BMEs support other clinicians in hospitals and work closely with clinicians to identify their needs and help them find the most suitable technology solutions. As a result of the special skills needed by BMEs working in health, there is a growing interest in registration and accreditation of BME/CEs for employment in NSW Health as has occurred in Queensland and elsewhere in the world.

The evolution of the BME/CE duties and functions from management and oversight of machine and device repair and maintenance to systems management and working with clinicians and patients to deliver health care solutions has given rise to a focus on a wide range of new competencies and skills, and the training for such skills through exposure to clinical health environments. It is clear that attention needs to be given to the BME/CE value-add “*in the patient care delivery process*.”

There are many challenges facing the BME/CE workforce in the next decade. The most significant being local recruitment and retention challenges, salary levels at senior levels, lack of adequate career pathways, the routine nature of the work, competition from private sector design and innovation work and from universities in relation to research. While entry level pay for new graduates is largely in line with or better than industry, this is not the case for more senior positions. This, coupled with limited career advancement opportunities, creates a significant retention issue for the health sector.

In short, at present there appears to be a demand side issue rather than a supply issue in relation to qualified BME recruitment. The growing interest in BME/CE from women engineers, the growth of the broader biotechnology sector and technology augmented patient-centred health care, provide a wide range of opportunities that could be explored by NSW Health to respond to the supply of BME graduates into the future. Pursuit of opportunities is critical given the turnover associated with the ageing BME workforce and the increasing demand for equipment in hospitals. The development of e-health and new personalised and networked devices provide immense opportunities for BMEs/CEs in health.

The key challenges to be addressed include:

- limited data and knowledge on the BME/CE workforce in NSW Health
- lack of clarity in definition of the BME/CE role in health and relatedly lack of validation and registration of BMEs/CEs for employment in health
- demographic factors, including the ageing BME & BMET workforce
- recruitment and retention tied to limited career pathways in NSW Health and lack of public awareness and appreciation of BME roles and opportunities in health
- limited training opportunities to prepare graduates for health employment
- advances in medical technology and e-health
- efficient provision and deployment of BME/CE staff across NSW Health LHDs.

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Appendices

Appendix A: Participant Pseudonyms and Their Sector of Employment

Table 4—List of Key Informant Pseudonyms used in this Report

Pseudonym	Sector
Jamie	Health Sector
Pat	Higher Education
Alex	Health Sector
Sam	Health Sector
Charlie	Higher Education
Taylor	Higher Education
Adrian	Health Sector
Andy	Higher Education
Blake	Higher Education
Frankie	Health Sector
Morgan	Health Sector
Drew	Health Sector

Appendix B: List of Biomedical Engineering tertiary education providers

Institution	Course Name	Course Type	Years Full Time	Link
Queensland University of Technology (QUT)	Bachelor of Engineering (Hons) (Medical)	Bachelor	4	https://www.qut.edu.au/courses/bachelor-of-engineering-honours-medical
The University of Queensland (UQ)	BE(Hons) Electrical and Biomedical Engineering	Bachelor	4	https://my.uq.edu.au/programs-courses/plan_display.html?acad_plan=ELBIOW2342
Flinders University	Bachelor of Engineering (Biomedical) (Hons)	Bachelor	4	https://www.flinders.edu.au/study/courses/bachelor-engineering-biomedical-honours
Flinders University	Master of Engineering (Biomedical)	Master	2	https://www.flinders.edu.au/study/courses/postgraduate-engineering-biomedical
Griffith University	*Mentioned in WHO report - discontinued now*			
La Trobe University	*Mentioned in WHO report - discontinued now*			
Monash University	Engineering and Biomedical Science	Bachelor (Double Degree)	5	https://www.monash.edu/study/courses/find-a-course/2019/engineering-and-biomedical-science
Monash University	Medical Engineering	Master	2	http://monash.edu/pubs/2019handbooks/aos/medical-engineering/
Murdoch University	*Mentioned in WHO report - discontinued now*			
Royal Melbourne Institute of Technology (RMIT)	Bachelor of Engineering (Biomedical Engineering) (Hons)	Bachelor	4	https://www.rmit.edu.au/study-with-us/levels-of-study/undergraduate-study/honours-degrees/bachelor-of-engineering-biomedical-engineering-honours-bh069

Institution	Course Name	Course Type	Years Full Time	Link
Royal Melbourne Institute of Technology (RMIT)	Master of Engineering (Electrical and Electronic Engineering)	Master	2	https://www.rmit.edu.au/study-with-us/levels-of-study/research-programs/masters-by-research/master-of-engineering-electrical--electronic-engineering-mr220
Swinburne University of Technology	Bachelor of Engineering (Hons) - Major in Biomedical	Bachelor	4	https://www.swinburne.edu.au/study/course/bachelor-of-engineering-honours/biomedical/
Swinburne University of Technology	Bachelor of Engineering (Hons) (Professional) - Major in Biomedical	Bachelor (including 1-year work experience)	5	https://www.swinburne.edu.au/study/course/bachelor-of-engineering-honours-professional/biomedical/
Swinburne University of Technology	Master of Engineering (Research) - specialise in Biomed	Master	2	https://www.swinburne.edu.au/study/course/Master-of-Engineering-(Research)-MR-ENG/local
University of Adelaide	Master of Philosophy (Research) - specialise in Biomed	Master	2	https://www.adelaide.edu.au/cbme/
University of Melbourne	Bachelor of Science (Bioengineering Systems)	Bachelor	3	https://study.unimelb.edu.au/find/courses/major/bioengineering-systems/
University of Melbourne	Master of Engineering (Biomedical) - follows above	Master	3	https://study.unimelb.edu.au/find/courses/graduate/master-of-engineering-biomedical/
University of Melbourne	Master of Engineering (Biomedical with Business)	Master	3	https://study.unimelb.edu.au/find/courses/graduate/master-of-engineering-biomedical-with-business/
University of New South Wales	Bachelor of Engineering (9 traditional majors) Combined with Master of Biomedical Engineering	Bachelor and Master combined	5	https://www.engineering.unsw.edu.au/study-with-us/undergraduate-degrees/biomedical-engineering
University of Technology Sydney (UTS)	Bachelor of Engineering (Honours) - Major in Biomedical	Bachelor	4	https://www.uts.edu.au/future-students/engineering/courses/undergraduate-majors/biomedical-engineering

Institution	Course Name	Course Type	Years Full Time	Link
University of Sydney	Bachelor of Engineering Honours (Biomedical) with 23 different majors - listed below	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Chemical Engineering	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Computational Engineering	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Computer Engineering	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Construction Management	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Energy and the Environment	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Engineering Design	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Environmental Engineering	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Fluids Engineering	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Geotechnical Engineering	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html

Institution	Course Name	Course Type	Years Full Time	Link
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Humanitarian Engineering	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Information Technology	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Internet of Things	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Materials Science & Engineering	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Mechanical Engineering	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Mechatronic Engineering	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Power Engineering	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Process Intensification	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Robotics and Intelligent Systems	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Structures	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html

Institution	Course Name	Course Type	Years Full Time	Link
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Telecommunication Engineering	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Transport Engineering	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html
University of Sydney	Bachelor of Engineering Honours (Biomedical) Major in Water and Environment Treatment	Bachelor	4	https://sydney.edu.au/courses/courses/uc/bachelor-of-engineering-honours-biomedical.html

Appendix C: Engineers Australia Competency Standards

Stage 1 Competency Standard for Professional Engineer

Stage 2 Experienced Professional Engineer

Stage 3 Engineering leadership and management competencies

STAGE 1 COMPETENCY STANDARD FOR PROFESSIONAL ENGINEER

ROLE DESCRIPTION - THE MATURE, PROFESSIONAL ENGINEER

The following characterises the senior practice role that the mature Professional Engineer may be expected to fulfil and has been extracted from the role portrayed in the *Engineers Australia - Chartered Status Handbook*. This is the expectation of the development of the engineer who on graduation satisfied the Stage 1 Competency Standard for Professional Engineer.

Professional Engineers are required to take responsibility for engineering projects and programs in the most far-reaching sense. This includes the reliable functioning of all materials, components, sub-systems and technologies used; their integration to form a complete, sustainable and self-consistent system; and all interactions between the technical system and the context within which it functions. The latter includes understanding the requirements of clients, wide ranging stakeholders and of society as a whole; working to optimise social, environmental and economic outcomes over the full lifetime of the engineering product or program; interacting effectively with other disciplines, professions and people; and ensuring that the engineering contribution is properly integrated into the totality of the undertaking. Professional Engineers are responsible for interpreting technological possibilities to society, business and government; and for ensuring as far as possible that policy decisions are properly informed by such possibilities and consequences, and that costs, risks and limitations are properly understood as the desirable outcomes.

Professional Engineers are responsible for bringing knowledge to bear from multiple sources to develop solutions to complex problems and issues, for ensuring that technical and non-technical considerations are properly integrated, and for managing risk as well as sustainability issues. While the outcomes of engineering have physical forms, the work of Professional Engineers is predominantly intellectual in nature. In a technical sense, Professional Engineers are primarily concerned with the advancement of technologies and with the development of new technologies and their applications through innovation, creativity and change. Professional Engineers may conduct research concerned with advancing the science of engineering and with developing new principles and technologies within a broad engineering discipline. Alternatively, they may contribute to continual improvement in the practice of engineering, and in devising and updating the codes and standards that govern it.

Professional Engineers have a particular responsibility for ensuring that all aspects of a project are soundly based in theory and fundamental principle, and for understanding clearly how new developments relate to established practice and experience and to other disciplines with which they may interact. One hallmark of a professional is the capacity to break new ground in an informed, responsible and sustainable fashion.

Professional Engineers may lead or manage teams appropriate to these activities, and may establish their own companies or move into senior management roles in engineering and related enterprises.

STAGE 1 COMPETENCIES

The three Stage 1 Competencies are covered by 16 mandatory Elements of Competency. The Competencies and Elements of Competency represent the profession's expression of the knowledge and skill base, engineering application abilities, and professional skills, values and attitudes that **must be demonstrated** at the point of entry to practice.

The suggested indicators of attainment in Tables 1, 2 and 3 provide insight to the breadth and depth of ability expected for each element of competency and thus guide the competency demonstration and assessment processes as well as curriculum design. The indicators should not be interpreted as discrete sub-elements of competency mandated for individual audit. Each element of competency must be tested in a holistic sense, and there may well be additional indicator statements that could complement those listed.

Definitions of terms used in the statements of the Competencies and Elements of Competency are consistent with those used by the International Engineering Alliance in Section 4 *Common Range and Contextual Definitions* of *Graduate Attributes and Professional Competencies Version 3: 21 June 2013*.

STAGE 1 COMPETENCIES and ELEMENTS OF COMPETENCY

1. KNOWLEDGE AND SKILL BASE

1.1. **Comprehensive, theory based understanding** of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline.

1.2. **Conceptual understanding** of the mathematics, numerical analysis, statistics, and computer and information sciences which underpin the engineering discipline.

1.3. **In-depth understanding** of specialist bodies of knowledge within the engineering discipline.

1.4. **Discernment** of knowledge development and research directions within the engineering discipline.

1.5. **Knowledge** of engineering design practice and contextual factors impacting the engineering discipline.

1.6. **Understanding** of the scope, principles, norms, accountabilities and bounds of sustainable engineering practice in the specific discipline.

2. ENGINEERING APPLICATION ABILITY

2.1. **Application** of established engineering methods to complex engineering problem solving.

2.2. **Fluent application** of engineering techniques, tools and resources.

2.3. **Application** of systematic engineering synthesis and design processes.

2.4. **Application** of systematic approaches to the conduct and management of engineering projects.

3. PROFESSIONAL AND PERSONAL ATTRIBUTES

3.1. **Ethical** conduct and professional accountability.

3.2. **Effective** oral and written communication in professional and lay domains.

3.3. **Creative**, innovative and pro-active demeanour.

3.4. **Professional** use and management of information.

3.5. **Orderly** management of self, and professional conduct.

3.6. **Effective** team membership and team leadership.

<u>Table 1</u> Knowledge and Skill Base: Elements and Indicators

ELEMENT OF COMPETENCY	INDICATORS OF ATTAINMENT
1.1 Comprehensive, theory based understanding of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline.	**a) Engages** with the engineering discipline at a phenomenological level, applying sciences and engineering fundamentals to systematic investigation, interpretation, analysis and innovative solution of *complex* problems and broader aspects of engineering practice.
1.2 Conceptual understanding of the mathematics, numerical analysis, statistics, and computer and information sciences which underpin the engineering discipline.	**a) Develops and fluently applies** relevant investigation analysis, interpretation, assessment, characterisation, prediction, evaluation, modelling, decision making, measurement, evaluation, knowledge management and communication tools and techniques pertinent to the engineering discipline.
1.3 In-depth understanding of specialist bodies of knowledge within the engineering discipline.	**a) Proficiently applies** advanced technical knowledge and skills in at least one specialist practice domain of the engineering discipline.
1.4 Discernment of knowledge development and research directions within the engineering discipline.	**a) Identifies and critically appraises** current developments, advanced technologies, emerging issues and interdisciplinary linkages in at least one specialist practice domain of the engineering discipline. **b) Interprets and applies** selected research literature to inform engineering application in at least one specialist domain of the engineering discipline.
1.5 Knowledge of engineering design practice and contextual factors impacting the engineering discipline.	**a) Identifies and applies** systematic principles of engineering design relevant to the engineering discipline. **b) Identifies and understands** the interactions between engineering systems and people in the social, cultural, environmental, commercial, legal and political contexts in which they operate, including both the positive role of engineering in sustainable development and the potentially adverse impacts of engineering activity in the engineering discipline. **c) Appreciates** the issues associated with international engineering practice and global operating contexts. **d) Is aware of** the founding principles of human factors relevant to the engineering discipline. **e) Is aware of** the fundamentals of business and enterprise management. **f) Identifies** the structure, roles and capabilities of the engineering workforce.
1.6 Understanding of the scope, principles, norms, accountabilities and bounds of sustainable engineering practice in the specific discipline.	**a) Appreciates** the basis and relevance of standards and codes of practice, as well as legislative and statutory requirements applicable to the engineering discipline. **b) Appreciates** the principles of safety engineering, risk management and the health and safety responsibilities of the professional engineer, including legislative requirements applicable to the engineering discipline. **c) Appreciates** the social, environmental and economic principles of sustainable engineering practice. **d) Understands** the fundamental principles of engineering project management as a basis for planning, organising and managing resources. **e) Appreciates** the formal structures and methodologies of systems engineering as a holistic basis for managing complexity and sustainability in engineering practice.

<u>Notes</u>:

1. *'engineering discipline' means the broad branch of engineering (civil, electrical, mechanical, etc.) as typically represented by the Engineers Australia Colleges.*
2. *'specialist practice domain' means the specific area of knowledge and practice within an engineering discipline, such as geotechnics, power systems, manufacturing, etc.*

<u>Table 2</u> Engineering Application Ability: Elements and Indicators

ELEMENT OF COMPETENCY	INDICATORS OF ATTAINMENT
2.1 Application of established engineering methods to *complex* engineering problem solving.	**a) Identifies, discerns and characterises** salient issues, **determines and analyses** causes and effects, **justifies and applies** appropriate simplifying assumptions, **predicts** performance and behaviour, **synthesises** solution strategies and **develops** substantiated conclusions. **b) Ensures** that all aspects of an engineering activity are soundly based on fundamental principles - by diagnosing, and taking appropriate action with data, calculations, results, proposals, processes, practices, and documented information that may be ill-founded, illogical, erroneous, unreliable or unrealistic. **c) Competently addresses** complex engineering problems which involve uncertainty, ambiguity, imprecise information and wide-ranging and sometimes conflicting technical and non-technical factors. **d) Investigates** complex problems using research-based knowledge and research methods. **e) Partitions** problems, processes or systems into manageable elements for the purposes of analysis, modelling or design and then **re-combines** to form a whole, with the integrity and performance of the overall system as the paramount consideration. **f) Conceptualises** alternative engineering approaches and **evaluates** potential outcomes against appropriate criteria to justify an optimal solution choice. **g) Critically reviews and applies** relevant standards and codes of practice underpinning the engineering discipline and nominated specialisations. **h) Identifies, quantifies, mitigates and manages** technical, health, environmental, safety and other contextual risks associated with engineering application in the designated engineering discipline. **i) Interprets and ensures** compliance with relevant legislative and statutory requirements applicable to the engineering discipline.
2.2 Fluent application of engineering techniques, tools and resources.	**a) Proficiently identifies, selects and applies** the materials, components, devices, systems, processes, resources, plant and equipment relevant to the engineering discipline. **b) Constructs or selects and applies** from a qualitative description of a phenomenon, process, system, component or device a mathematical, physical or computational model based on fundamental scientific principles and justifiable simplifying assumptions. **c) Determines** properties, performance, safe working limits, failure modes, and other inherent parameters of materials, components and systems relevant to the engineering discipline. **d) Applies** a wide range of engineering tools for analysis, simulation, visualisation, synthesis and design, including assessing the accuracy and limitations of such tools, and validation of their results. **e) Applies** formal systems engineering methods to address the planning and execution of complex, problem solving and engineering projects. **f) Designs and conducts** experiments, **analyses and interprets** result data and **formulates** reliable conclusions. **g) Analyses** sources of error in applied models and experiments; eliminates, **minimises or compensates** for such errors; **quantifies** significance of errors to any conclusions drawn. **h) Safely applies** laboratory, test and experimental procedures appropriate to the engineering discipline. **i) Understands** the need for systematic management of the acquisition, commissioning, operation, upgrade, monitoring and maintenance of engineering plant, facilities, equipment and systems. **j) Understands** the role of quality management systems, tools and processes within a culture of continuous improvement.

Table 2 (cont.) Engineering Application Ability: Elements and Indicators

ELEMENT OF COMPETENCY	INDICATORS OF ATTAINMENT
2.3 Application of systematic engineering synthesis and design processes.	**a) Proficiently applies** technical knowledge and open ended problem solving skills as well as appropriate tools and resources to design components, elements, systems, plant, facilities and/or processes to satisfy user requirements. **b) Addresses** broad contextual constraints such as social, cultural, environmental, commercial, legal political and human factors, as well as health, safety and sustainability imperatives as an integral part of the design process. **c) Executes and leads** a whole systems design cycle approach including tasks such as: - determining client requirements and identifying the impact of relevant contextual factors, including business planning and costing targets; - systematically addressing sustainability criteria; - working within projected development, production and implementation constraints; - eliciting, scoping and documenting the required outcomes of the design task and defining acceptance criteria; - identifying assessing and managing technical, health and safety risks integral to the design process; - writing engineering specifications, that fully satisfy the formal requirements; - ensuring compliance with essential engineering standards and codes of practice; - partitioning the design task into appropriate modular, functional elements; that can be separately addressed and subsequently integrated through defined interfaces; - identifying and analysing possible design approaches and justifying an optimal approach; - developing and completing the design using appropriate engineering principles, tools, and processes; - integrating functional elements to form a coherent design solution; - quantifying the materials, components, systems, equipment, facilities, engineering resources and operating arrangements needed for implementation of the solution; - checking the design solution for each element and the integrated system against the engineering specifications; - devising and documenting tests that will verify performance of the elements and the integrated realisation; - prototyping/implementing the design solution and verifying performance against specification; - documenting, commissioning and reporting the design outcome. **d) Is aware of** the accountabilities of the professional engineer in relation to the 'design authority' role.
2.4 Application of systematic approaches to the conduct and management of engineering projects.	**a) Contributes to and/or manages** *complex* engineering project activity, as a member and/or as the leader of an engineering team. **b) Seeks out** the requirements and associated resources and **realistically assesses** the scope, dimensions, scale of effort and indicative costs of a *complex* engineering project. **c) Accommodates** relevant contextual issues into all phases of engineering project work, including the fundamentals of business planning and financial management **d) Proficiently applies** basic systems engineering and/or project management tools and processes to the planning and execution of project work, targeting the delivery of a significant outcome to a professional standard. **e) Is aware of** the need to plan and quantify performance over the full life-cycle of a project, managing engineering performance within the overall implementation context. **f) Demonstrates** commitment to sustainable engineering practices and the achievement of sustainable outcomes in all facets of engineering project work.

<u>Table 3</u> Professional and Personal Attributes: Elements and Indicators

ELEMENT OF COMPETENCY	INDICATORS OF ATTAINMENT
3.1 **Ethical** conduct and professional accountability.	**a)** **Demonstrates** commitment to uphold the Engineers Australia - Code of Ethics, and established norms of professional conduct pertinent to the engineering discipline. **b)** **Understands** the need for ‘due-diligence’ in certification, compliance and risk management processes. **c)** **Understands** the accountabilities of the professional engineer and the broader engineering team for the safety of other people and for protection of the environment. **d)** **Is aware of** the fundamental principles of intellectual property rights and protection.
3.2 **Effective** oral and written communication in professional and lay domains.	**a)** **Is proficient in** listening, speaking, reading and writing English, including: - comprehending critically and fairly the viewpoints of others; - expressing information effectively and succinctly, issuing instruction, engaging in discussion, presenting arguments and justification, debating and negotiating - to technical and non-technical audiences and using textual, diagrammatic, pictorial and graphical media best suited to the context; - representing an engineering position, or the engineering profession at large to the broader community; - appreciating the impact of body language, personal behaviour and other non-verbal communication processes, as well as the fundamentals of human social behaviour and their cross-cultural differences. **b)** **Prepares** high quality engineering documents such as progress and project reports, reports of investigations and feasibility studies, proposals, specifications, design records, drawings, technical descriptions and presentations pertinent to the engineering discipline.
3.3 **Creative**, innovative and pro-active demeanour.	**a)** **Applies** creative approaches to identify and develop alternative concepts, solutions and procedures, appropriately challenges engineering practices from technical and non-technical viewpoints; identifies new technological opportunities. **b)** **Seeks out** new developments in the engineering discipline and specialisations and **applies** fundamental knowledge and systematic processes to evaluate and report potential. **c)** **Is aware of** broader fields of science, engineering, technology and commerce from which new ideas and interfaces may be drawn and readily **engages** with professionals from these fields to exchange ideas.
3.4 **Professional** use and management of information.	**a)** **Is proficient in** locating and utilising information - including accessing, systematically searching, analysing, evaluating and referencing relevant published works and data; is proficient in the use of indexes, bibliographic databases and other search facilities. **b)** **Critically assesses** the accuracy, reliability and authenticity of information. **c)** **Is aware of** common document identification, tracking and control procedures.
3.5 **Orderly** management of self, and professional conduct.	**a)** **Demonstrates** commitment to critical self-review and performance evaluation against appropriate criteria as a primary means of tracking personal development needs and achievements. **b)** **Understands** the importance of being a member of a professional and intellectual community, learning from its knowledge and standards, and contributing to their maintenance and advancement. **c)** **Demonstrates** commitment to life-long learning and professional development. **d)** **Manages** time and processes effectively**, prioritises** competing demands to achieve personal, career and organisational goals and objectives. **e)** **Thinks critically and applies** an appropriate balance of logic and intellectual criteria to analysis, judgement and decision making. **f)** **Presents** a professional image in all circumstances, including relations with clients, stakeholders, as well as with professional and technical colleagues across wide ranging disciplines.
3.6 **Effective** team membership and team leadership.	**a)** **Understands** the fundamentals of team dynamics and leadership. **b)** **Functions as** an effective member or leader of diverse engineering teams, including those with multi-level, multi-disciplinary and multi-cultural dimensions. **c)** **Earns** the trust and confidence of colleagues through competent and timely completion of tasks. **d)** **Recognises** the value of alternative and diverse viewpoints, scholarly advice and the importance of professional networking. **e)** **Confidently pursues and discerns** expert assistance and professional advice. **f)** **Takes initiative and fulfils** the leadership role whilst respecting the agreed roles of others.

AUSTRALIAN ENGINEERING COMPETENCY STANDARDS STAGE 2 - EXPERIENCED PROFESSIONAL ENGINEER

The Stage 2 Competency Standards are the profession's expression of the knowledge and skill base, engineering application abilities, and professional skills, values and attitudes that must be demonstrated in order to practise independently or unsupervised.

Purpose of the Stage 2 competency standards

The Stage 2 competency standards are used as the basis of assessment for Chartered membership of Engineers Australia (CPEng) and registration on the National Engineering Register (NER).

Chartered membership is exclusive to Engineers Australia. It is a professional credential recognised by government, business and the general public worldwide. The achievement of CPEng brings with it a career-long obligation to maintain competence in a chosen practice area.

What is expected of an experienced professional engineer?

The community has certain expectations of experienced professional engineers, their competence, how they apply this competence and how they will conduct themselves.

Experienced professional engineers:

- understand the requirements of clients, wide ranging stakeholders and of society as a whole
- work to optimise social, environmental and economic outcomes over the full lifetime of the engineering product or program
- interact effectively with other disciplines, professions and people
- ensure that the engineering contribution is properly integrated into the totality of the project, program or process
- are responsible for:
  - interpreting technological possibilities to society, business and government
  - ensuring, as far as possible, that policy decisions are properly informed by possibilities and consequences
  - ensuring that costs, risks and limitations are properly understood in the context of the desirable outcomes
  - bringing knowledge to bear from multiple sources to develop solutions to complex problems and issues
  - ensuring that technical and non-technical considerations are properly integrated
  - managing risk as well as sustainability issues
  - ensuring that all aspects of a project, program or process are soundly based in theory and fundamental principle
  - for understanding clearly how new developments relate to established practice and experience and to other disciplines with which they may interact

While the outcomes of engineering generally have physical forms, the work of experienced professional engineers recognises the interaction between people and technology. Professional engineers may conduct research concerned with advancing the science of engineering and with developing new principles and technologies within a broad engineering discipline. Alternatively, they may contribute to the education of engineers, continual improvement in the practice of engineering and to devising and updating the codes and standards that govern it.

Stage 2 competency standards

The Stage 2 competency standards are generic in the sense that they apply to all disciplines of engineering in four units:

- personal commitment
- obligation to community
- value in the workplace
- technical proficiency

Each unit contains elements of competence and indicators of attainment. The elements of competence are the capabilities necessary to the unit of competence and the indicators of attainment serve as a guide to the engineering work likely to be considered as demonstrating attainment of that competence.

Demonstration of competence – Professional Engineer

The demonstration of competence requires the presentation of written accounts of work that involves engineering contributions – contributions based on the bodies of knowledge associated with established engineering practice and engineering science. Many aspects of engineering practice may be based on well-established but unpublished guidelines, or even practices that are not commonly documented or written but learned through the experience of practice under the guidance and supervision of a more experienced engineer.

When selecting work experience to offer as evidence of competence, provide examples of contributions to work that has some or all of the characteristics of either an *engineering problem* or *engineering activity* as described below:

Engineering problems

- Involve wide-ranging or conflicting technical, sociological, environmental and other requirements
- Have no obvious solution and require abstract thinking and originality in analysis to formulate suitable models
- Require the application of first principles
- Involve infrequently encountered issues
- Have complex or conflicting stakeholder requirements and consequences that involve diverse groups of stakeholders with widely varying needs
- Can be dissected into component parts or sub-problems
- Require the creation of successful, timely engineering solutions.

Engineering activities

- Involve the coordination of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies) in the timely delivery of outcomes
- Require resolution of significant problems arising from interactions between wide-ranging or conflicting technical, sociological, environmental or other requirements
- Involve creative use of engineering principles and knowledge, much of which is at, or informed by, the forefront of a practice area
- Have significant consequences in a range of contexts, characterised by difficulty of prediction and mitigation
- Can extend beyond previous experiences by applying first principles
- Require the achievement of successful outcomes on time and on budget.

At any particular time, a professional engineer applying for Stage 2 assessment would expect some areas to be developing with others at a functional or proficient level as described below.

- Developing: an aspect of practice that you are learning, with help from more experienced practitioners and possibly supervision to help you practice at an acceptable standard.
- Functional: an aspect of practice in which you have a basic capability to practice independently at an acceptable standard without help or supervision.
- Proficient: an aspect of practice in which your capability to practice independently has been recognised through formal peer review, and in which you have the capacity to help others develop their capability.

A successful assessment at Stage 2 will formalise a transfer from functional to proficient.

ENGINEERS AUSTRALIA

AUSTRALIAN ENGINEERING COMPETENCY STANDARDS STAGE 2 – PROFESSIONAL ENGINEER

Elements of Competence – PERSONAL COMMITMENT

This unit of competence requires you to demonstrate:

- how you deal with ethical issues when they arise
- how you develop and define your areas of competence
- how you display a personal sense of responsibility for your work

ELEMENT OF COMPETENCE – PROFESSIONAL ENGINEER	**What this competence means in practice**	**Indicators of Attainment** Refer to only as many Indicators of Attainment as you need to demonstrate the Element of Competence
1. Deal with ethical issues	*means* you anticipate the consequences of your intended action or inaction and understand how the consequences are managed collectively by your organisation, project or team; and *means* you demonstrate an ability to identify ethical issues when they arise and to act appropriately	• appraise and respond appropriately to ethical dilemmas in your practice area • recognise an unethical situation; take appropriate action • engage in ethical reflective practice • seek appropriate advice and consult Engineers Australia Code of Ethics
2. Practise competently	*means you* assess, acquire and apply the competencies and resources appropriate to *engineering activities*	• regularly assess your own competence (in the absence of assessment by more experienced engineers) and continually acquire new knowledge and skills • maintain a concise description of your areas of competence • carry out engineering work only within the boundaries of your known areas of competence • maintain records of Continuing Professional Development activities
3. Responsibility for *engineering activities*	*means* you display a personal sense of responsibility for your work; and *means* you clearly acknowledge your own contributions and the contributions from others and distinguish contributions you may have made as a result of discussions or collaboration with other people	• consistently document work in a way that would enable another person of comparable ability to continue and complete your work should you be unable to do so due to circumstances beyond your control • seek peer reviews and comments of your own contributions, and make improvements to work based on their suggestions • provide reviews and constructive comments to help others improve their own work • authorise engineering outputs only on the basis of an informed understanding of the costs, risks, consequences and limitations

Elements of Competence – OBLIGATION TO COMMUNITY

'Community' will change depending on the nature of the work you are doing. Sometimes it will be the client; sometimes the general public; sometimes your students; sometimes the regulatory authorities and sometimes it will be your employer. This unit of competence requires you to demonstrate:

- how you delivered a safe and sustainable solutions
- how you defined the community and considered the community benefit at various stages of *engineering activities* (within the context of your work)
- how you identified and managed the risks associated with the engineering activities
- how you incorporated legal and regulatory requirements into your solutions

ELEMENT OF COMPETENCE – PROFESSIONAL ENGINEER	**What this competence means in practice**	**Indicators of Attainment** Refer to only as many Indicators of Attainment as you need to demonstrate the Element of Competence
4. Develop safe and sustainable solutions	*means* that you apply and implement current workplace health and safety requirements; and *means* that you identify the economic, social and environmental impacts of *engineering activities; and* *means* that you anticipate and manage the short and long-term effects of *engineering activities*	• provide for the safety of workers and others in design, manufacture, construction, commissioning, use, decommissioning, demolition, removal and disposal of plant, products, substances or structures • take into account well-accepted standards of practice for design safety, while making the most economic use of financial, human effort, energy and material resources • develop designs or solutions to engineering problems that balance the impact of present engineering activities with the economic, social and environmental prospects of future generations • manage engineering activities to enhance the economic, social and environmental prospects of future generations
5. Engage with the relevant community and stakeholders	*means* you identify stakeholders, individuals or groups of people who could be affected by the short, medium and long-term outcomes of *engineering activities*, or could exert influence over the engineered outcomes, including the local and wider community; and *means* you identify stakeholder interests, values, requirements and expectations using the terminology of the stakeholder through consultation and accurate listening; and *means* you work ethically to influence perceptions and expectations of stakeholders and negotiate acceptable outcomes in the best overall interest of relevant communities.	• consider safety, environmental, public health and other public interest issues relevant to the *engineering activities* • engage responsibly with appropriate communities to convey information on the consequences of *engineering activities* and potential solutions to *engineering problems* • take into account the reliance of others on engineering expertise when engaging with the community

ELEMENT OF COMPETENCE – PROFESSIONAL ENGINEER	**What this competence means in practice**	**Indicators of Attainment** Refer to only as many Indicators of Attainment as you need to demonstrate the Element of Competence
6. Identify, assess and manage risks	*means* that you develop and operate within a hazard and risk framework appropriate to *engineering activities*	• identify, assess and manage product, project, process, environmental or system risks that could be caused by material, economic, social or environmental factors • establish and maintain a documented audit trail of technical and operational changes during system or product development, project implementation or process operations • follow a systematic documented method and work in consultation with stakeholders and other informed people to identify unpredictable events (threats, opportunities, and other sources of uncertainty or missing information) that could influence outcomes • assess the likelihood of each event, and the consequences, including commercial, reputation, safety, health, environment, regulatory, legal, governance, and social consequences • devise ways to influence the likelihood and consequences to minimise costs and undesirable consequences, and maximise benefits • help in negotiating equitable ways to share any costs and benefits between stakeholders and the community
7. Meet legal and regulatory requirements	*means* that you should be able to demonstrate an understanding of the laws, regulations, codes and other instruments which you are legally bound to apply, and apply these in your work	• identify and comply with the codes, standards of compliance or legal instruments relevant to a particular product, project, process or system • draft commercial contracts that cover the procurement of services, equipment, materials, access rights or access to information • seek advice, rulings or opinions from time to time to ensure that your understanding of legal and regulatory requirements is up-to-date • practise within legal and regulatory requirements • negotiate appropriate approvals from regulatory authorities for *engineering activities* • protect intellectual property

Elements of Competence – VALUE IN THE WORKPLACE

This unit of competency requires you to demonstrate:

- how you collaborate and work with others
- how you work within an organisation to provide value for stakeholders
- how you initiate, plan, lead or manage and secure financial and other material resources to support *engineering activities*
- how you apply your professional judgement

ELEMENT OF COMPETENCE – PROFESSIONAL ENGINEER	**What this competence means in practice**	**Indicators of Attainment** Refer to only as many Indicators of Attainment as you need to demonstrate the Element of Competence
8. Communication	*means* you can communicate in a variety of different ways to collaborate with other people, including accurate listening, reading and comprehension, based on dialogue when appropriate; and *means* you can speak and write, taking into account the knowledge, expectations, requirements, interests, terminology and language of the intended audience	• respect confidentiality obligations • build and maintain collaborative relationships with other people, gaining their respect, trust, confidence and willing, conscientious collaboration • exercise informal leadership in order to coordinate the activities of diverse people who contribute to *engineering activities* • collaborate effectively within multi-disciplinary teams including other professions in the workplace • lead and sustain discussion with others and, where appropriate, integrate their views to improve deliverables • convey new concepts and ideas to technical and non-technical stakeholders • deliver clear written and oral presentations on engineering problems and engineering activities in English or in a language appropriate to the engineering work.

ELEMENT OF COMPETENCE – PROFESSIONAL ENGINEER	What this competence means in practice	Indicators of Attainment Refer to only as many Indicators of Attainment as you need to demonstrate the Element of Competence
9. Performance	*means* that you demonstrate an ability to apply appropriate tools or processes to achieve corporate objectives while accounting for personal obligations to the profession	• build, develop and maintain relationships with product, project, process or system clients, sponsors, partners, service providers and contractors • dialogue with a client, sponsor, organisation, government or other social actors to jointly develop an accurate understanding of needs, opportunities and priorities • work with a client, sponsor, organisation, government or other social actors to develop solutions in terms of engineering possibilities • cultivate an attitude of engineering innovation and creativity to add value for clients or sponsors of the product, project, process or system • apply engineering performance requirements that create the greatest benefits or value for stakeholders, keeping in mind the tolerance for uncertainty of different stakeholders that are providing financial or other material resources in the anticipation of future benefits. [Performance requirements could include the need to keep to a desired schedule, long-term cost effectiveness, minimising upfront capital expense, accelerated financial returns or social or environmental benefits, technical quality, constructability, maintainability and operational reliability, among others] • collaborate within and outside educational institutions to enhance the quality and value of engineering education to students • question the contract or agreement that governs your work, and ensure that it allows for the possibility that you may not be able to complete the work due to circumstances beyond your control

ELEMENT OF COMPETENCE – PROFESSIONAL ENGINEER	**What this competence means in practice**	**Indicators of Attainment** Refer to only as many Indicators of Attainment as you need to demonstrate the Element of Competence
10. Taking action	*means* that you initiate, plan, lead or manage *engineering activities*	• contribute to successful proposals, bids, technical qualification and tender documents for *engineering activities* • provide initiative and leadership in coordinating technical, commercial, social and environmental aspects of *engineering activities* implementation • gain sufficient confidence from stakeholders for them to provide you with financial and other resources to conduct your work independently on the understanding that you will deliver agreed results on time within a given cost target • apply and use appropriate formal coordination and management systems and organisational processes such as project management, quality management, production management, logistics, enterprise resource and planning systems, maintenance management, configuration management, information management • report progress relative to the agreed schedule, expenditure relative to the budget, provide agreed deliverables, and report on any outstanding issues • manage projects effectively, including scoping, procurement and integration of physical resources and people; control of cost, quality, safety, environment and risk; and monitoring of progress and finalisation of projects • keep financial and other records to substantiate the effective application of finance and other resources provided in support of your work, in a form that is appropriate to meet the needs of agencies that will audit the conduct of the work
11. Judgement	*means* that you exercise sound judgement in *engineering activities*	• deal decisively with *engineering activities* which have significant consequences and diverse or conflicting stakeholder interests • supervise, monitor and evaluate the progress of technical work performed by other people, diagnose performance deficiencies and negotiate appropriate remedial measures, such as providing training and assistance • seek appropriate advice and decide whether to proceed or suspend work when faced with unexpected obstacles, performance deficiencies, impending or actual failures

Elements of Competence – TECHNICAL PROFICIENCY

This unit of competency require you to demonstrate:

- how you use advanced engineering science
- how you make effective use of engineering knowledge provided by other people
- how you analyse problems and how you develop creative and innovative solutions
- how you evaluate the outcomes and impacts of engineering activities

ELEMENT OF COMPETENCE – PROFESSIONAL ENGINEER	**What this competence means in practice**	**Indicators of Attainment** Refer to only as many Indicators of Attainment as you need to demonstrate the Element of Competence
12. Advanced engineering knowledge	*means* that you comprehend and apply advanced theory-based understanding of engineering fundamentals to predict the effect of *engineering activities*	• Develop and apply current research papers to inform and shape perceptions of engineering possibilities to meet [client] needs • apply advanced theory-based knowledge of engineering fundamentals and the forefront of a practice area to the delivery of engineering projects, systems and programs (including educational) • use mathematical, numerical and computational tools pertinent to the engineering discipline to predict technical, commercial, environmental and social performance • apply the principles and theories of engineering science and mathematics to help make accurate performance predictions, including predicting failure • apply engineering fundamentals and logic to the development and operation of complex financial, commercial or managerial systems
13. Local engineering knowledge	*means* that you acquire and apply local engineering knowledge; and *means* that, where appropriate, you apply engineering knowledge contributed by other people including suppliers, consultants, contractors and independent experts	• apply accepted local technical literature and engineering practices and locally applied international standards • take into account local environmental plans, conditions, constraints and opportunities • when appropriate, apply and incorporate engineering knowledge embodied in standards, design guides, product datasheets, existing products and designs in order to produce reliable and economic results in a timely manner • keep yourself informed about new and emerging technologies, techniques, products, materials, methods, theories and science relevant to your practice areas • apply Australian knowledge and practices, including unwritten engineering knowledge contributed by informed peers and experts knowledgeable in the area of engineering

ELEMENT OF COMPETENCE – PROFESSIONAL ENGINEER	**What this competence means in practice**	**Indicators of Attainment** Refer to only as many Indicators of Attainment as you need to demonstrate the Element of Competence
14. Problem analysis	*means* that you define, investigate and analyse *engineering problems* and opportunities	• accurately determine the main issues that require addressing in analysing the problem and reliably identify opportunities to improve outcomes • work with customer or employer to reach an agreed understanding of the expected capability or functionality of the required product, project, process or system • when you identify or are presented with *engineering problems*, adopt appropriate research methods to locate previously known solutions to similar problems, including seeking advice or help from informed people • conduct research, investigation and analysis in relation to product, project, process or system • adopt educational best practice and inclusive principles in the design and delivery of educational programs and courses • engage in dialogue with appropriate people to reach an agreed understanding of technical issues for which there are no well-understood and reliable solutions
15. Creativity and innovation	*means* that you develop creative and innovative solutions to *engineering problems*	• apply your knowledge of materials and physical and abstract objects to work out how to rearrange them so they perform the required function • develop the most effective ways to create value for sponsors, clients, end users and investors in products, projects, processes or systems that have agreed aesthetics, level of performance or properties • select and use fundamental principles to meet requirements economically, possibly reusing or modifying existing componentry • develop concepts to meet requirements and specify, document, build, test, verify, validate, measure and monitor engineering products or processes • review opportunities in work portfolio for enhancing products, processes, systems and services, assesses viability and initiate actions • apply the benefits of continuous technical change and innovation to enhance the outcomes delivered • apply and advance research-based education practice to course design, delivery and assessment

ELEMENT OF COMPETENCE – PROFESSIONAL ENGINEER	**What this competence means in practice**	**Indicators of Attainment** Refer to only as many Indicators of Attainment as you need to demonstrate the Element of Competence
16. Evaluation	*means* that you evaluate the outcomes and impacts of *engineering activities*	• evaluate ongoing projects, products and processes to identify and diagnose performance deficiencies, impending or actual failures, and propose remedies and solutions • monitor and evaluate product, project, process or system against whole of life criteria (cost, quality, safety, reliability, maintenance, aesthetics, fitness for purpose and social and environmental impact and decommissioning) • determine criteria for evaluating a design solution and address designer obligations for work health and safety • undertake and report design verification (e.g. of pressure equipment) to required standard • set or adopt criteria for evaluation and review and evaluate the effectiveness of engineering programs • evaluate product, project, process or systems outcomes against the original specification or design brief • diagnose performance deficiencies, conceive and design remedial measures and predict performance of modified systems • evaluate product, project, process or systems outcomes for constructability and maintainability as input to future design improvement • assess and use technical information and statistics correctly to ensure that opportunities are based on sound evidence • engage in periodic review and continuous improvement of educational programs and courses

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ENGINEERS AUSTRALIA

STAGE 3 – ENGINEERING LEADERSHIP AND MANAGEMENT COMPETENCIES

Units of Competency

Unit 1 – Leadership

Element	Indicative defining activities
1.1 Exercise personal attributes of leadership	1.1.1 Purpose and values are established 1.1.2 Creativity and innovation employed 1.1.3 Integrity, sincerity of purpose and values are communicated 1.1.4 Strengths of others are capitalised on 1.1.5 Teams are successfully developed and lead 1.1.6 Natural personal leadership style/type is recognised 1.1.7 Leadership style is adjusted to suit context 1.1.8 Written and oral skills are effectively used 1.1.9 Negotiation and mediation skills are employed
1.2 Exercise leadership in organisations	1.2.1 Vision for organisation identified and communicated 1.2.2 Strategy and actions are planned and implemented using recognised principles 1.2.3 Creativity/innovation processes are used (eg Simplex Model) 1.2.4 A process approach is used in realising and monitoring progress of organisational objectives 1.2.5 Appropriate organisational structures are adopted for achieving desired outcomes 1.2.6 Desired organisational values are identified and deployed 1.2.7 Leadership and management concepts , tools and techniques are appropriately selected and employed to enhance leadership, eg: - Strategic plans - Business plans - Risk management plans - Performance management - Performance appraisals - Management reviews - Reporting regimes - Corrective and preventive action - Reward systems - Training/educational needs assessments and delivery programs

1.3 Appreciate stakeholders	1.3.1 Needs and expectations of stakeholders relating to the business are identified and addressed, including in regard to: - Owners - Customers - Employees - Community 1.3.2 External factors are appreciated and appropriately addressed, including in regard to: - Community - Legislative/regulatory - Political - Safety - Environmental
1.4 Promote the Engineering profession	1.4.1 Engineering profession promoted 1.4.2 Professional leadership demonstrated 1.4.3 Development of the profession advocated on behalf of Engineers Australia
1.5 Display creativity	1.5.1 Creativity is encouraged 1.5.2 Management styles that foster creativity are selected and employed 1.5.3 Different methods for being creative are employed 1.5.4 Creativity sessions are contributed to 1.5.5 Innovation teams are facilitated 1.5.6 The inter-relationship between organisational structures and creativity is managed 1.5.7 Staff are selected and deployed so as to enable/encourage creativity and innovation
1.6 Manage workplace change	1.6.1 Understanding of change is encouraged 1.6.2 Changes/Improvements are planned and implemented

Unit 2 – Strategic Direction and Entrepreneurship

Element	Indicative defining activities
2.1 Provide strategic direction and display entrepreneurship.	2.1.1 New business opportunities and ideas are identified 2.1.2 New business initiatives are championed 2.1.3 Strategic direction and objectives are identified and communicated eg in regard to customers and suppliers 2.1.4 Supporters for enterprises are identified and recruited, eg joint venture participants 2.1.5 Contacts for the success of the business venture are identified and realised
2.2 Embrace new technology	2.2.1 Measures to identify new technology are employed 2.2.2 Adoption of new technology is evaluated 2.2.3 New technology is introduced
2.3 Assess feasibility	2.3.1 Possible ventures are compared, including in financial terms 2.3.2 Present value techniques are used 2.3.3 Financial judgements are made
2.4 Appreciate risk	2.4.1 Business risks are identified and appreciated

2.5 Establish business financing	2.5.1 Finance sources for new ventures are identified 2.5.2 Financing arrangements are evaluated 2.5.3 Finance is secured
2.6 Recognise importance of personnel aspects	2.6.1 A future outlook in staff encouraged 2.6.2 Corporate core competencies are identified and nurtured (corporate core competencies are a limited number of corporate capabilities that customers value, are mutually reinforcing and difficult to imitate)
2.7 Establish business structures	2.7.1 New business structures are identified 2.7.2 New business staffing is identified 2.7.3 New business organisational processes are identified

Unit 3 – Planning

Element	Indicative defining activities
3.1 Undertake business planning	3.1.1 Vision and objectives are appreciated 3.1.2 Current context and external environment are assessed and documented (business, economic and/or political) 3.1.3 SWOT analyses are undertaken 3.1.4 Critical success factors are identified and addressed 3.1.5 Customers needs and expectations are identified and addressed 3.1.6 Strategic and business plans are documented, tested and acceptance of them gained 3.1.7 Implementation of plans is set up and monitored in a structured way 3.1.8 Performance is measured, monitored and reported against agreed criteria 3.1.9 Plans are reviewed and updated
3.2 Manage risk	3.2.1 Risk management plans developed, implemented and improved
3.3 Undertake market planning	3.3.1 Customers' current and future needs are identified 3.3.2 Market segments are identified and value assessed 3.3.3 Marketing plans are developed, including plans/strategies for: • Identifying and assessing competition, • Retaining existing customers and engaging additional customers, • Branding promotion, • Product or service range, • Distributing products or services
3.4 Undertake operational planning	3.4.1 Operational (eg annual, product, service and project) plans* are established in alignment with strategic and business planning 3.4.2 Performance indicators to monitor the progressive and final implementation of plans are established 3.4.3 Performance indicators are assessed for effectiveness 3.4.4 Plans are set up and co-ordinated 3.4.5 Implementation of plans is monitored in a structured way 3.4.6 Performance is measured, monitored and reported against agreed criteria 3.4.7 Plans are updated when needed

3.5 Undertake resource planning	3.5.1 Resource plans for human resources, supporting infrastructure (eg workspace, process equipment, hardware, software and communication services) and the work environment are prepared in line with strategic and business plans 3.5.2 Technology plans are prepared in support of strategic, business and operational plans etc 3.5.3 Implementation of resource and technology plans is set up and monitored in a structured way 3.5.4 Performance is measured, monitored and reported against agreed criteria 3.5.5 Resource plans and technology plans are updated

* Operational Plans typically include supporting plans for managing matters such as scope, program, cost, risk and technical and other compliance.

Unit 4 – Change and Improvement

Element	Indicative defining activities
4.1 Review organizational performance and identify improvement opportunities.	4.1.1 Processes for review of organisational performance are identified, planned and set up 4.1.2 Pertinent information on organisational performance is identified and collected 4.1.3 Performance is assessed against pre-established performance criteria and targets 4.1.4 Inferior performance and other improvement opportunities are identified and recorded 4.1.5 Superior performance is acknowledged and success rewarded
4.2 Plan improvements	4.2.1 Causes of inferior performance are determined and risks are assessed to support decision-making process 4.2.2 Improvement opportunities are agreed and are prioritised by a suitable method 4.2.3 Measurable objectives are established for each improvement project 4.2.4 Implementation actions, responsibilities and timescales for completion are determined 4.2.5 Resources for improvement projects are identified and provided
4.3 Implement improvements	4.3.1 Improvement projects are implemented 4.3.2 Progress (towards measurable objectives) are regularly reviewed and monitored and interventions taken as appropriate
4.4 Verify effectiveness of improvements	4.4.1 Improvement projects are verified as complete 4.4.2 Measurable objectives for the project are achieved 4.4.3 Planned improvements in operational performance are realised

Unit 5 – Customer Focus *(Note: Customers may be internal to the organisation.)*

Element	Indicative defining activities
5.1 Research customers.	5.1.1 Customers are identified 5.1.2 Customers' pertinent attributes are identified
5.2 Manage communication with customers	5.2.1 Customers' requirements are identified 5.2.2 Unclear requirements are clarified 5.2.3 Feedback and complaints are effectively addressed
5.3 Assess customer satisfaction	5.3.1 Customer satisfaction is measured 5.3.2 Results of customer satisfaction measurement used in design of products and processes.

Unit 6 - Processes, Products and Services

Element	Indicative defining activities
6.1 Employ innovation (How the individual acquires, evaluates and implements creative ideas to accelerate business)	6.1.1 Innovative ideas are harvested for processes 6.1.2 Innovative ideas are recognised and supported, eg allocated resources 6.1.3 Ideas are selected and converted to assist in the satisfaction of customer expectations 6.1.4 Research and new technology and techniques are utilised in developing ideas 6.1.5 Processes are identified, developed and designed (including improvements to existing processes) so the best process is used for the task at hand 6.1.6 Needs and expectations of customers (existing and potential) are met when developing new ideas.
6.2 Manage improvement (How the individual manages and improves processes- is there a structured approach)	6.2.1 Processes and their inter-relationships are identified; 6.2.2 Processes (including verification processes) are planned; 6.2.3 Briefing/induction and training needs for personnel undertaking processes are identified 6.2.4 Personnel are briefed/inducted and trained in use of processes; 6.2.5 Inputs for processes are identified reviewed for adequacy; 6.2.6 Criteria for acceptability of outputs defined; 6.2.7 Outputs are reviewed for compliance; 6.2.8 Performance measures are established and achievement monitored; 6.2.9 Contributions and participation in improvements encouraged; 6.2.10 Improvement processes used (See Unit 4) 6.2.11 Internal customers satisfied (see also customer/client focus); 6.2.12 Internal customer relationships are identified and managed to achieve external customer satisfaction; 6.2.13 There are standardised processes; 6.2.14 Regulations and Standards are reviewed and complied with and processes are suitably modified; 6.2.15 Benchmarking is used for comparison and learning.

6.3 Apply quality measures to service and products (What quality indicators are used to compare performance against standards, customer expectations and competitors)	6.3.1 Quality indicators for in-process and attribute measures relating to customer requirements are established and reviewed; 6.3.2 Performance levels of processes are established and used to ensure agreed specifications can be met; 6.3.3 Comparison of products and services with competitors is used (particularly the best performers) to improve the quality, including identification, definition and setting up and monitoring of assessment/measuring techniques.

Unit 7 – People/Human Resources

Element	Indicative defining activities
7.1.Manage self	7.1.1 Personal career goals and objectives are identified and their attainment planned and monitored; 7.1.2 Personal strengths are identified and capitalised on 7.1.3 Personal weaknesses are identified and managed 7.1.4 Strategies to sustain personal motivation and effectiveness are established and implemented 7.1.5 Use of time is managed 7.1.6 Self understanding is appreciated and demonstrated in communication with others 7.1.7 Listening and assertive skills are used
7.2 Behave ethically	7.2.1 Understanding of ethical behaviours is appreciated and demonstrated (including in regard to its importance to organisational image and reputation, team moral, trust and customer satisfaction).
7.3 Recruit employees	7.3.1 The organisation's personnel recruitment needs are identified. 7.3.2 Strategies for recruiting required personnel are determined and implemented. 7.3.3 Criteria and processes for recruitment of personnel are established 7.3.4 Personnel are assessed against criteria and recruited
7.4 Manage employees	7.4.1 Performance targets, commensurate with organisational targets are agreed with personnel 7.4.2 Personnel performance regularly assessed against targets 7.4.3 Counselling on poor performance undertaken 7.4.4 Training and development plans agreed with personnel and their implementation monitored (Plans should include building on strengths and addressing weaknesses.) 7.4.5 Measures are taken to develop the strengths of staff and address their weaknesses eg job rotation, mentoring
7.5 Dismiss employees	7.5.1 Equitable processes used for the dismissal of personnel
7.6 Promote well being and morale	7.6.1 Workplace health and safety provided for employees 7.6.2 Effective personnel feedback mechanisms established, used and reinforced through responsiveness 7.6.3 Equity and diversity strategies developed and implemented 7.6.4 Processes for handling of harassment complaints by personnel established

Unit 8 – Supplier Relationships

(Note: The term "supplier" in this context refers to suppliers in general, including providers of consultancy services, plant, equipment, materials and constructed works. Suppliers may be internal or external to the organisation.)

Element	Indicative defining activities
8.1 Develop supplier strategy	8.1.1 Strategy for purchasing and relationship with suppliers are established and implemented
8.2 Select suppliers	8.2.1 Process and criteria for selection of suppliers are defined and established 8.2.2 Suppliers selected to criteria and engaged 8.2.3 Feedback and complaints are effectively addressed and matters assessed for identifying potential improvements
8.3 Specify requirements	8.3.1 Adequate documents for engagement of suppliers (purchasing documents) are developed, reviewed and approved 8.3.2 Changes to purchasing documents/requirements are managed
8.4 Undertake surveillance/ monitoring	8.4.1 Surveillance/monitoring of suppliers is planned and performed to provide appropriate level of confidence that requirements are met 8.4.2 Planned surveillance/monitoring utilises appropriate approaches (eg quality control and/or quality assurance) 8.4.3 Assessed performance of supplier (including results of surveillance) is made known to supplier recorded and used in selections and planning of surveillance

Unit 9 – Information

Element	Indicative defining activities
9.1 Identify & source information needs	9.1.1 The information needs of individuals/teams is determined and the resources are identified 9.1.2 Information held by the organisation is reviewed to determine suitability and accessibility 9.1.3 Plans are prepared to obtain information which is not available/accessible within the organisation
9.2 Collect, analyse and report information	9.2.1 Collection of information is timely and relevant to the needs of individuals/teams 9.2.2 Information is in a format suitable for analysis, interpretation and dissemination 9.2.3 Information is analysed to identify and report relevant trends and developments in terms of the needs for which it was acquired
9.3 Use management information systems and document control systems.	9.3.1 Management information systems and document control systems are used effectively to store and retrieve data for decision making 9.3.2 Technology available in the work area/organisation. is used to manage information effectively and efficiently 9.3.3 Recommendations for improving the information system are submitted to designated persons/groups
9.4 Prepare submissions	9.4.1 Individuals/teams are involved in business plan/budget and other submission preparation in a way which uses their contribution effectively and gains their support for the outcomes 9.4.2 Business plans/budgets and other submissions are presented in accordance with the organisation's guidelines and requirements

9.5 Manage intellectual property	9.5.1 Intellectual property of others is identified and used in a lawful manner 9.5.2 Intellectual property of the organisation is protected and managed in an appropriate manner
9.6 Work with legal documents and systems	9.6.1 Working with legal material is undertaken 9.6.2 Understanding of the legal structures of a business (ie the law of association) is exercised 9.6.3 Understanding of the significant features of the law relating to employment and dispute resolution procedures is exercised 9.6.4 Understanding of basic contract law relevant to the business (including management of variations, dispute resolution and arbitration) is exercised 9.6.5 Knowledge of the law relating to independent contractors is exercised 9.6.6 Knowledge of the law relating to occupational health and safety, workers compensation and rehabilitation is exercised 9.6.7 Knowledge of the law relating to conservation of the environment is exercised 9.6.8 Understanding of relevant aspects of Taxation law is exercised 9.6.9 Freedom of information law is complied with
9.7 Use Standards	9.7.1 Australian, International and other Standards are used as appropriate

10. Finance, Accounting and Administration

Element	Indicative defining activities
10.1 Handle financing	10.1.1 Financial viability of proposals are assessed, including rate of return 10.1.2 Funding sources are identified and assessed 10.1.3 Financial strategies are developed and implemented 10.1.4 Financial position, financial performance and cash flow statements are used 10.1.5 Financial viability of organisations are assessed 10.1.6 Financial performance is monitored
10.2 Manage accounts	10.2.1 Income and expenditure are planned and monitored 10.2.2 Cash flow budgets are prepared 10.2.3 Budget Controls are understood and used 10.2.4 Costing information identified and used 10.2.5 Familiarity with elements of accounts payable system demonstrated 10.2.6 Familiarity with elements of accounts receivable system demonstrated 10.2.7 Familiarity with elements of the payroll system demonstrated 10.2.8 Familiarity with elements of asset management system demonstrated

10.3 Manage auditing	10.3.1 Purpose and methodology of audits understood and involvement in audits managed. Audits may relate to following • Financial • Quality • Environment • Occupational Health and Safety • Risk management • Corporate governance
10.4 Exercise fraud control	10.4.1 Strategies for the prevention of fraud are established and implemented 10.4.2 Accountable financial and business processes are employed 10.4.3 Incidents investigated and corrective action implemented
10.5 Manage health and safety	10.5.1 Occupational Health and Safety principles understood and implemented 10.5.2 Injury and dangerous occurrences reported 10.5.3 Incidents investigated and corrective action implemented