Biomedical Engineering Education in Nigeria: Emergence, Challenges, Prospects and Areas for Development

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Abstract

In the past five decades, Nigeria has witnessed a range of Biomedical Engineering (BME) and technology activities within private and public hospitals, research institutions, and a limited number of universities. These have mainly centred on the procurement, installation, and maintenance of medical equipment and devices. Trained technologists and technicians, equipped with relevant skills and certification, have primarily spearheaded these efforts. Consequently, the country has made a minimal contribution to the global knowledge base in BME research. However, academic programmes leading to degrees and dedicated research in BME have recently emerged within Nigerian universities. This article assesses the current state of BME education in the country, including the milestones achieved, ongoing challenges, and prospects for future development. It draws on a critical analysis of the existing literature on BME practices and education in Nigeria as well as the author's informed perspective. The findings highlight that BME education in Nigeria is yet to match international standards. To further develop these programmes, it recommends that attention focus on seven key areas that have proven instrumental in the development of similar university programmes in developed nations. Strategies are also proposed to foster collaboration among universities, researchers, the health sector, and government entities that would promote interdisciplinary BME education, ultimately enhancing the healthcare delivery system, and research and development (R&D) in Nigeria.

Key words: academic programme, biomedical engineering, biomedical education, biomedical in Nigeria, Nigerian healthcare.

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Sommaire

Au cours des cinq dernières décennies, le Nigeria a connu une série d'activités d'ingénierie biomédicale et de technologie au sein d'hôpitaux privés et publics, d'instituts de recherche et d'un nombre limité d'universités. Ces activités sont principalement axées sur l'acquisition, l'installation et la maintenance d'équipements et de dispositifs médicaux. Des technologues et des techniciens formés, dotés de compétences et de certifications appropriées, ont été les principaux fers de lance de ces efforts. Par conséquent, le pays n'a apporté qu'une contribution minimale à la base de connaissances mondiale en matière de recherche sur les BME. Toutefois, des programmes académiques menant à des diplômes et à des recherches spécifiques en BME ont récemment vu le jour dans les universités nigérianes. Cet article évalue l'état actuel de l'enseignement des BME dans le pays, y compris les étapes franchies, les défis actuels et les perspectives de développement futur. Il s'appuie sur une analyse critique de la littérature existante sur les pratiques et l'enseignement des BME au Nigeria, ainsi que sur le point de vue éclairé de l'auteur. Les conclusions soulignent que l'enseignement des BME au Nigeria n'est pas encore conforme aux normes internationales. Les conclusions soulignent que l'enseignement des BME au Nigeria n'est pas encore à la hauteur des normes internationales. Pour développer davantage ces programmes, il est recommandé de se concentrer sur sept domaines clés qui se sont avérés déterminants dans le développement de programmes universitaires similaires dans les pays développés. Des stratégies sont également proposées pour favoriser la collaboration entre les universités, les chercheurs, le secteur de la santé et les entités gouvernementales, afin de promouvoir l'enseignement interdisciplinaire des sciences de la vie et de la médecine, et d'améliorer en fin de compte le système de prestation des soins de santé et la recherche et le développement (R&D) au Nigeria.

Mots clés: programme universitaire, ingénierie biomédicale, éducation biomédicale, biomédecine au Nigéria, soins de santé au Nigéria

Introduction

Biomedical engineering (BME) is one of the leading interdisciplinary engineering fields across the world. In integrating expertise in biology, medicine and engineering, not only does it promote collaborative healthcare activities between clinicians, researchers, and engineers, but also highlights the vital role played by engineering in physical and physiological studies of biological systems (Harris et al., 2002). The growth of BME over the past few decades has made a significant contribution to global medical diagnosis and treatment, leading to an improved quality of life. However, Nigeria is lagging behind in exploring the potential of this field, especially at the educational level. Although the country has been home to BME activities for decades, they were not tailored towards academic programmes. The majority, which are mostly handled by trained mechanical and electrical technicians, involve the installation, maintenance and replacement of medical tools in hospitals (Coker et al., 2015). Few university students or staff have produced scientific research publications in this field despite the fact that some universities/colleges have offered BME programmes for decades.

An obvious reason is that most practicing biomedical engineers and professionals in Nigeria are not trained to conduct research. The majority of BME programmes produce professionals who work in the medical devices and equipment industry (Bamigboye and Bello, 2020). This focus is understandable given that, when BME training was first offered at the University of Lagos in the 1980s, the country's population of around 74 million had access to few medical facilities. However, attention is now shifting from clinical practice to BME programmes with an interdisciplinary curriculum and research for national growth. The increasing health issues in Nigeria due to pollution, poverty and stress, as well as the amount lost to medical tourism each year, have highlighted the need for home-grown researchers in this field.

Steady progress has been made in this direction, including training provided to lecturers at the Universities of Ibadan and Lagos by the Northwestern University BME growth programme for sub-Saharan Africa, through a grant from the National Institutes of Health's Fogarty International Center in the US (Coker at al., 2015). At the American Society for Engineering Education (ASEE) International Forum held in June 2016 in New Orleans, it was reported that 12 researchers from the University of Ibadan and 11 from the University of Lagos in the College of Medicine, and Faculties of Engineering, Science, Education and Economics had received training to foster interdisciplinary BME programmes in Nigeria (Gatchell et al., 2016). However, BME education in Nigeria is in its developmental stage.

Daniel and Muhammad (2014) provided an extensive analysis of the challenges confronting BME education and practice in developing countries, particularly the lack of technology and infrastructure. Okorie (2015) noted the need for Nigerian universities to offer such education and asserted that collaborative research by hospital staff and BME students would improve healthcare in the country. Kingsley Akarowhe (2018) focused on the ongoing challenges facing BME research in the country, including the fact that the medical data available in some Nigerian hospitals are inadequate and incorrect. Odeyemi et al. (2019) called for more research to be undertaken by Nigerian academics in general, highlighting biomedical research as one of the key areas. Bashiru and Bashir (2020) concurred and identified a number of misconceptions that stymie such efforts.

The literature as well as a number of national and international conferences and forums have proposed strategies to remedy this situation (Nkuma-Udah et at., 2015). It is against this background that this article identifies the issues that need to be addressed for the successful establishment of BME education in Nigeria.

BME Education and Research in Nigeria

Biomedical engineering education is a vital aspect of medical education across the world (Magjarevic et al., 2010), with universities and research organisations focusing on this field (Gehlot, 2009; Douglas, 2011). While BME activities in Nigeria can be said to have started in the 1970s, professional activities commenced with the collaborative efforts of the Universities of Lagos and Liverpool in 1982. This resulted in the establishment of the BME department in the former's College of Medicine. Its primary focus was on management of hospitals' medical equipment and engineering facilities (Nkuma-Udah et al., 2015). Similar programmes were established at Ahmadu Bellow University, Zairia, in 1993 and University College Hospital (UCH), Ibadan, in 1996 (https://uch-ibadan.org.ng/non-clinical-2/) to train technologists and technicians

to install and repair devices for medical procedures. However, they were not designed to nurture the expertise required for scientific research. A shift occurred with the establishment of a Biomedical Technology department at the Federal University of Technology, Owerri in 2007 and the launch of the first undergraduate programme in BME at the University of Ilorin in 2016.

The mission of the Nigerian Institute for BME (NIBE), which was established in 1999 is "to develop and advance the biomedical science, health and human well-being of Nigeria through modern technological approaches comparable to those obtainable in any developed country of the world." Biomedical engineering research in Nigeria is expected to cover five areas of human health and research, namely, biological engineering, medical engineering, clinical engineering, rehabilitation engineering, and biomedical physics/allied sciences (Voigt and Magjarević, 2014). However, given that most BME activities in the country continue to focus on servicing industry and health institutions, degree programmes leading to research in these specialisations tended to be limited to clinical and rehabilitation engineering; the earliest and still the most popular programme in Nigeria.

Several factors account for late acknowledgement of the value of BME in Nigeria. The lack of academic expertise among home-based researchers in the field, a shortage of funds to establish state-of-art facilities and infrastructure, and limited training for faculty and students are among the most important (Schneiber et al., 2010). However, some universities in Nigeria have taken up the challenge to create enabling environments for BME degree programmes that would facilitate interdisciplinary research. Different universities now offer academic undergraduate BME programmes relating to different areas of specialisation such as bioinformatics, biomaterials, biomechanics, and cellular and tissue engineering, among others. Table 1 lists these universities, the BME degree offered, and the year the programmes commenced. The data for this table were sourced from the respective school websites and the Internet at the time of writing this article.

Table 1: Nigerian universities with BME programmes

Universities/colleges	BME degree	Commencement	Host faculty
Achievers University, Owo	B.Eng.	2017	College of Engineering and Technology
Afe Babalola University	B.Eng.	2017	College of Engineering
Bells University, Ota	B.Eng.	2009	College of Engineering
Federal University of Technology, Owerri	B.Tech#	2022	School of Engineering and Engineering Technology
First Technical University, Ibadan	B.Eng.	2017	Faculty of Engineering and Technology
State University of Medical and Applied Sciences	B.Eng.	2015	Faculty of Engineering and Built Environment
University of Lagos	B.Eng., PGD, MSc	2017, 2012, 2013	Faculty of Engineering
University of Ibadan	BSc*, MSc, PhD	*, 2017, 2023	Faculty of Technology
University of Ilorin	B.Eng.	2010	Faculty of Engineering & Technology
University of Portharcourt	B.Tech		School of Science Laboratory

**BSc programme curriculum submitted to the university senate for ratification.*
#FUTO recently launched a BME programme in the School of Engineering and Engineering Technology and discontinued the Biomedical Technology programme in the School of Health and Health Technology.

Furthermore, an exploratory literature review on BME research in Nigeria points to significant efforts in the areas of biomaterials, biomechanics, cardiovascular and biofluid mechanics, bio instrumentation, the physical and mechanical behaviour of tissues treated on engineering materials, artificial intelligence, implantable devices and finite element models (Okorie, 2015). Research has been conducted on a diagnostic tool for obesity related issues (Vincent et al., 2019; Owolabi et al., 2021; Jilantikiri et al., 2022), rehabilitation (Fidelis and Arowolo, 2023), respiratory and cardiovascular biomechanics (Ayodele et al., 2021; Oyejide et al., 2023; Ige et al., 2023), biomaterials and tissue engineering (Ebenezer et al., 2023; Joy et al., 2022), bio-instrumentation (Yahaya et al., 2019), medical artificial intelligence (Zaccheus et al., 2023; Nwaneri and Ugo, 2022; Zaccheus et al., 2023), healthcare technology (Oyejide et al., 2023; Ige et al., 2023;) and biofluid mechanics (Ayodele et al., 2022; Fetuga et al., 2023).

Why Embrace BME Academic Programmes in Nigeria?

Nigeria is one of the few African countries with reasonably well-organised BME practice (Oluwadare, 2020). As the country that is home to the largest number of universities on the continent, it is expected to join the league of countries in the world with standard BME education. Daniel and Muhammad (2018) assert that, "Academics from developing countries must add their knowledge and experience to the ever-growing knowledge-pool of BME research." However, given that significant BME practice in most developing countries such as Nigeria has focused on technical training in relation to medical devices and equipment, how do academics from such countries make a meaningful contribution to the global knowledge pool of BME research? Developed countries not only tackle global health issues, but have also conducted extensive research on those that are peculiar to developing countries. For example, for more than two decades, a World Health Organization (WHO)-United Nations Children's Fund (UNICEF) partnership has invested millions of dollars in providing testing kits and drugs for malaria (Tan, 2016); Department for International Development, 2010). The COVID-19 pandemic is another case in point (Akinlabi et al., 2022). According to Brooking Report (2020), prior to the outbreak, there were just 350 ventilators in Nigeria. Furthermore, tracking those infected with the virus was a challenge due to limited technologies and equipment (Oyejide et al., 2023), undermining the authenticity of recorded and confirmed cases. Facilities and expert human resources, including biomedical engineers and researchers are thus required to prepare the country for future pandemics.

While the Nigerian government is committed to strengthening the healthcare system, especially laboratory capacity, scant attention has been paid to biomedical research. This resulted in local biomedical engineers and researchers playing a limited role in the prevention and treatment of malaria and COVID-19. Developing BME academic programmes would enable Nigeria to achieve a reasonable level of self-reliance in tackling health issues. Such programmes would also create opportunities for Nigerian researchers to contribute to the global BME knowledge pool. This can be achieved through the provision of technological infrastructure and teaching and research based on rigorous, yet flexible classroom activities, laboratory studies, field testing, and research

presentations and publications. It would require collaboration between the government and the country's universities to develop standard BME educational programmes.

Challenges Confronting BME Research in Nigeria

Biomedical engineering research and education in Nigerian universities confront similar challenges to those arising in other fields of study and fellow developing countries.

Lack of an Enabling Research Environment

Nigerian universities produce many graduates with the capacity to conduct research each year; however, many opt to pursue further studies in developed countries that offer an enabling research environment and career prospects. The facilities and mentorship offered at universities abroad enable them to contribute to solution-based research. Moreover, Nigeria's high unemployment rate and state of insecurity have resulted in many ambitious, talented scholars in different professional fields seeking greener pastures. As BME education becomes more well-established in the country's universities, it is likely that graduates in this field will follow this trend.

Lack of State-of-the-Art Facilities

The Nigerian universities that offer BME programmes currently lack sophisticated, reliable research facilities. Only a few have dedicated laboratories for extensive in vivo and in vitro research. Many lack 3D printing machines to utilise materials such as scaffolds for tissue engineering and biomaterial research. Among other factors, this has led to low BME research output, especially in biology and medicine. A lack of state-of-the-art research facilities prevents researchers from making meaningful contributions to society. For instance, a parallel computational facility assists in modeling and simulations such as cardiovascular flow with no risk to humans and animals. Such a facility could also promote synergy between researchers in science and engineering. There is thus a need for BME departments to conduct research with the country's research institutes that offer access to such facilities. Funding could be sourced from national agencies, the Ministry of Health, and private organisations with research interests in this field. It is also important that students have supervised access to these facilities.

Lack of Funding/ Misappropriation

Nigerian universities confront funding challenges despite the government's efforts to provide funds for research and development. A lack of funding has prevented a number of research universities from setting up laboratories that meet international standards. Furthermore, misappropriation of funds by university staff is an on-going threat as corruption has eaten deep into Nigeria's educational system (Dawood, 2012; Oladele, 2019). National structures should be established to monitor educational funding.

Funding for biomedical research should be stepped up and quality research should be rewarded with monetary or other incentives (Nkuma-Udah et al., 2009). The availability of funds influences the quality and impact of research and this is an essential requirement for any research institution (Bashiru and Bashir, 2020).

Poor Infrastructure

Access to relevant literature and research is an important aspect of any effective educational programme (Abukutsa-Onyango, 2010). Nigeria's browsing facilities are not reliable and students and researchers have limited access in some universities, with others yet to make such provision for students. Although the majority of faculty in well-established universities have Internet facilities, poor bandwidth from network providers sometimes interrupts activities such as online lectures and meetings. The development of BME education in Nigeria requires access to up-to-date and complete data, as well as peer-reviewed literature and reports (Arai et al., 2007). Interruptions in electricity supply also mean that universities incur the cost of fueling generators. The power supply is sometimes rationed to save costs, leading to issues with preserving specimens and operating some equipment.

Lack of Trust in Home-trained, Home-based Biomedical Engineers

Like many of its African counterparts, Nigeria has depended on developed countries for medical technologies and healthcare for decades. Medical tourism costs Nigeria more than N576 billion each year (Gehlot, 2009; Abubakar et al., 2018). This is due to the fact, that first, the country lacks the required facilities and expertise. Second, optimal use is not made of local experts. Consequently, Nigerians travel abroad for treatment even if facilities are available. Lastly, the Nigerian medical sector prefers to engage the services of foreign engineers, sidelining locally trained engineers and researchers. This situation calls for the skills of BME graduates to be upgraded and for the medical sector and citizens to allow local engineers and researchers to prove their worth.

Lack of Access to Medical Data from Hospitals

According to Kingsley Akarowhe (2018), some Nigerian hospitals have poor record keeping systems, hampering research activities. Cultural norms and inflexible policies also prevent researchers from gaining access to medical records. The use of paper files rather than electronic medical information systems also stymies research. Resistance to adopting more modern methods is due to the belief that moving patients' records online would make some staff redundant. However, quality research with patient-specific impact requires that data be made easily available to researchers.

Accelerating BME Education in Nigeria

The BME programmes in some Nigerian universities are making progress while in others, structures are in the process of being put in place to commence such programmes. The following recommendations and strategies were identified to contribute to the development of BME in developed countries, and Nigeria in particular. Figure 1 summarises the recommendations.

Robust Undergraduate Curriculum

The curricula followed by many Nigerian universities result in many students cramming to pass without internalising the basic concepts of the course. The reason is that due to inadequate facilities, some practical aspects of courses are taught theoretically. To avoid this pitfall, BME programmes should include practical sessions that involve activities that reinforce the theories taught in lectures. The curriculum should be designed to equip students with the experience and research skills required for postgraduate studies. The programmes should thus include courses and practice that build their competence in the use of research tools such as imagining, numerical simulations, computational fluid dynamics, machine learning, bioinformatics, 3D printing, material characterisation, scientific computation, robotics and so on.

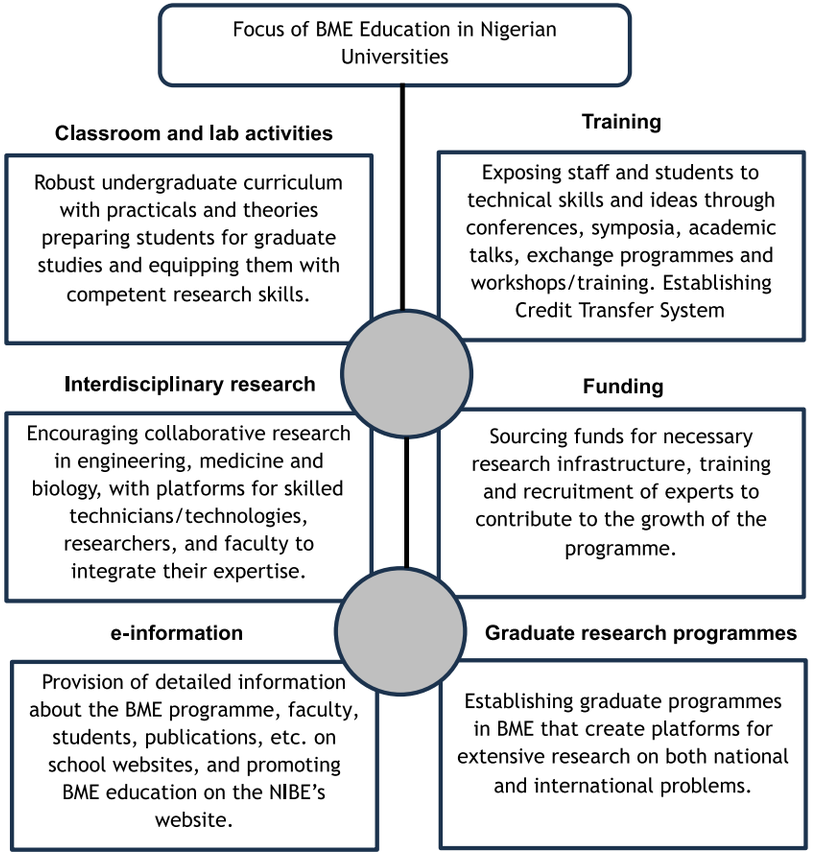

Figure 1: Key focus areas for the development of BME education in developed countries

Raising Awareness

The websites of BME departments in Nigerian universities lack full information on their faculty and research activities. This could discourage prospective students from enrolling in their programmes and international researchers from collaborating with them. University websites in developed countries provide sufficient information on the institution and its programmes. The NIBE could promote local programmes by having links on its website to academic institutions offering BME. The NIBE website should also include news articles on progress in BME in the country and research undertaken. Cooperation between the NIBE and universities with BME programmes could stimulate interest in interdisciplinary BME education. It would also assist in soliciting funding from state and federal programmes and encourage secondary school students to consider BME as a career. A good example of such an initiative is the University of Ibadan that exhibited its mechanical and BME innovations at the newly established UI Design Studio-Innovation hub in November 2021, sponsored by Rice University, Houston, Texas, USA, under the platform of NEST360 project. As a member of the department, I witnessed students' overwhelming interest in participating in the programme, including those from other engineering departments. Similar initiatives should be considered in other universities, and they should be publicised in the media in order to attract students and researchers from every corner of the country.

Training for Students and Faculty

An institution's development is generally achieved through training workshops, seminars, research and exchange visits with other universities (Abouelenein, 2016). Over the years, many established programmes in Nigerian universities have followed this trend, especially at graduate level. As a body with links to international organisations such as International Federation of Medical and Biological Engineering, the NIBE can leverage this platform to train Nigerian-based researchers. This could involve exchange programmes that empower students and lecturers with technical research skills. Universities should invest in BME conferences, symposia, academic talks, and workshops/training. Platforms should also be provided to encourage students and lecturers to conduct research and present the outcomes at conferences and meetings. An obvious benefit is the exchange of ideas between visiting and home-based researchers. This would offer Nigerian researchers the opportunity to brainstorm with researchers with access to top-notch research facilities and renowned faculty and thus expand the scope of knowledge and problem-solving techniques in the country (Bashiru and Bashir, 2018).

Research at Graduate Level

Core BME research is the domain of postgraduate researchers (Rajamohanan et al., 2015). Postgraduate training thus lays a scientific,

rational and ethical foundation for future research practice. Okorie (2015) noted that it is also essential for biomedical engineers to have considerable knowledge of both engineering and medical science, at least biology, as well as pursue their education to masters or doctoral level in order to develop interdisciplinary research capacity. A few schools offer BME at postgraduate level. As stated in its mission, the BME MSc programme at the University of Ibadan aims "To develop a skilled workforce capable of creating new biomedical industries and providing solutions to emerging local and global healthcare challenges." This points to an interdisciplinary stance that needs to be adopted by more institutions in the country. Encouraging research in BME at graduate level will not only attract researchers from other parts of Africa, but will also benefit the health sector as it will produce new knowledge on medical issues, especially those peculiar to Nigeria and the continent at large.

Interdisciplinary Research

The field of BME is a broad one that covers an array of disciplines. Moreover, it has evolved as a result of technological advancements as well as breakthroughs in other fields such as chemical engineering, computer science and engineering, and physics (Harris et al., 2002). Researchers are now able to investigate, monitor, and mitigate the severity of health challenges (Elliot et al., 2021). However, BME academic programmes in Nigeria have yet to expand their scope to cover the many areas of research pursued in universities in developed countries. This could be one reason why the country struggles to meet global standards in healthcare delivery. For example, at the University of Ibadan, faculty for the graduate BME programmes should come from several related fields like Pharmacy, Dentistry, Industrial, Mechanical, and Electrical Engineering, Mathematics, and Physiology, among others, and students should be paired with co-supervisors who can synchronise their expertise and work with students to conduct rich scientific research and produce high impact publications.

Focus on Specific National Challenges

Apart from being a degree programme, BME is generally expected to provide solutions to human health challenges. Therefore, BME education should inculcate problem-solving in students. Specific

national challenges should be the focus of research in this field, with students, faculty, and funding organisations collaborating to positively impact patients and society. For instance, many universities and private laboratories in developed countries have focused on diseases like cancer and cardiovascular disorders, with Masters, PhD, and post-doctoral researchers funded to contribute their expertise to findings solutions. This is not a common research pattern in Nigeria due to the fact that there are few medical research funding organisations and that the country's laboratories lack sufficient equipment to attract funding. Hence, research is often motivated by simply obtaining a degree. Given that many Nigerian researchers are achieving much with the limited resources available to them, I would argue that, if BME faculties focus on solution-based research, they will attract grants and will be able to recruit researchers to find solutions to the medical challenges confronting Africa and Nigeria such as malaria and cholera.

Short- and Long-Term Local Needs as an Initial Focus for BME Graduate Education

While most scholars and professionals have argued that insufficient funding (Oyibocha et al., 2014) and human resources (Salami et al., 2016) are primary issues in relation to healthcare in Nigeria, from a BME point of view, innovations in relation to medical devices, point-of-care diagnostics (POCD), telemedicine infrastructure, and healthcare data analytics are acute challenges. In the short term, innovations regarding medical devices and POCD can serve as focal points for BME graduate education. For instance, BME graduate programmes could focus on training students to design, develop, and adapt POCD technologies such as robust, affordable, and user-friendly devices that are well-suited to resource-constrained environments. In addition, given the electricity challenges in Nigeria (Leng et al., 2020; Adebayo and Ofoegbu, 2014), graduate students could engage in cutting-edge research aimed at designing energy-efficient and sustainable POCD devices.

However, its long-term vision is what will sustain BME education (Linsenmeier and Saterbak, 2020). As Nigeria strives to achieve universal healthcare access and to bolster its healthcare infrastructure, BME graduate education should embrace forward-thinking domains in areas such as telemedicine, electronic health records (EHR), health informatics,

medical imaging, data analytics, and mobile health applications. For instance, graduate students could be equipped with hands-on experience in developing remote patient monitoring systems that can track vital signs, chronic conditions, and other health parameters. According to Ayokunle et al. (2022), remote monitoring was a critical challenge in Nigeria during the COVID-19 pandemic. Similarly, graduate education could look into health data integration; training students to integrate EHR, patient monitoring data, and medical imaging into mHealth apps while adhering to data privacy and security standards. Such systems can enable continuous patient care and early intervention.

Recruitment of Faculty with Expertise, Especially with BME Backgrounds

A lack of sufficiently trained human resources is perhaps the greatest challenge confronting BME education in Nigeria. Most BME faculty are not academically trained in this field, with the majority from mechanical and electrical engineering and others from engineering, science and basic medical sciences. Their appointment is due to the fact that they are considered to have sufficient expertise to teach BME courses. While this could promote interdisciplinary research, their lack of a background in BME could also impose limitations on classroom teaching, especially for undergraduates.

Credit Transfer System

The European Credit Transfer System (ECTS) has demonstrated its efficacy in promoting academic mobility and collaboration within the European Union (Wagenaar, 2019; Serpa et al., 2020) and has been adopted across the globe (Hotta, 2020; Mirzayev, 2022). This strategic approach could facilitate students' seamless mobility between academic institutions, both within the country and internationally, while ensuring the acquisition of essential training and expertise (Pallikarakis et al., 2018; Mirzayev, 2022). Adopting a similar model could enable Nigerian BME students to harness the benefits of diverse educational offerings and distinctive institutional strengths. It would offer them a well-rounded, tailored educational experience while fostering cross-institutional partnerships that enrich the BME landscape in the country. Such a system would not only allow students to access specialised courses across various institutions, but also enable these institutions to

focus their resources and expertise on specific BME areas aligned with local needs.

A Credit Transfer System could pave the way for joint initiatives and the creation of dedicated engineering departments specialising in key BME domains. This approach aligns with the overarching goal of addressing the unique challenges and opportunities within Nigeria's healthcare and engineering sectors. Collaborative efforts would catalyse the development of a robust and versatile workforce (Chakpitak and Bouras, 2015) equipped to tackle complex biomedical challenges on both a local and global scale.

Active, Adaptive and Experiential Learning and Teaching

Furthermore, a profound opportunity arises at the intersection of BME education in Nigeria and the wealth of experience inherent in clinical engineering, specifically in the domain of medical equipment operation and maintenance. The global evolution of BME education encourages a reimagining of pedagogical approaches, embracing the principles of active, adaptive, and experiential learning and teaching as catalysts for curriculum innovation and interdisciplinary collaboration (Singh, 2017; Linsenmeier and Saterbak, 2020). The synergy between BME academics and clinical expertise holds tremendous potential to shape the BME curriculum to align with evolving healthcare demands, as well as facilitate the scheduling and logistics of courses and the continuity of the concepts delivered (Siewerdsen, 2020). Methodologies that actively engage students through problem-solving, group discussions, and hands-on projects (Hernández-de-Menéndez et al., 2019) can bridge the theoretical-practical gap, fostering deeper understanding of the intricacies of medical equipment and technology. Such an approach not only imparts technical proficiency but also cultivates the critical thinking and decision-making skills that are vital to address complex healthcare challenges.

Adaptive learning, with its personalised and data-driven instructional design, is able to tailor educational experiences to individual students' needs, optimising knowledge acquisition and retention (Singh, 2017). It can also be harnessed to accommodate diverse learning paces and styles within the BME cohort, facilitating comprehensive skills development. Moreover, incorporation of experiential learning mechanisms such

as internships, practical workshops, and clinical rotations can forge a robust connection between engineering and clinical institutes. Nigerian BME undergraduate students normally undergo mandatory six-month industrial training before returning for their final-year projects. This time should be used to immerse students in real-world healthcare settings to gain firsthand insights into clinical workflows, patient care dynamics, and the practical implications of BME solutions. Discussions on curriculum in developed countries (White et al., 2020; Seow et al., 2019) suggest that a combination of active, adaptive, and experiential learning methodologies could serve as a dynamic force in BME education in Nigeria, enabling curriculum development that bridges disciplinary boundaries and enhances the proficiency of future biomedical engineers.

Prospects of BME Education in Nigeria

Given Nigerian BME academic programmes' steady progress and the interest shown by more universities in offering the programme, BME education is likely to gain ground. As universities roll out competent graduates in this field, the Nigerian BME industry will need to expand to accommodate them. In turn, universities will need to expand their programmes as more undergraduates and graduates show interest in them. This will increase the need for faculty, providing job opportunities for graduates of BME programmes. Likewise, as the BME programme finds its way into almost all accredited universities in Nigeria, lecturers will need to conduct quality research to remain relevant. Ultimately, as Nigerian universities contribute to global health solutions, the programme will gain international attention through grants, exchange programmes, collaboration and training, leading to national development and an improved healthcare system.

Conclusion

Nigeria is one of the few African countries to have recorded relative progress in the establishment of BME education. To entrench and expand such progress, BME needs to navigate the transition from clinical engineering practice to robust, innovative academic programmes in universities. To achieve this milestone, medical doctors, hospital managers, ministries of health, the government, technologists and the NIBE should share a common aspiration to improve biomedical education and enable Nigeria to take the lead in biomedical research. As the government, hospitals, research institutes and universities continue to work towards tackling the ongoing challenges of BME education and research in the country, quality attention and resources should be devoted to the issues discussed in this article, namely, the need for a robust undergraduate curriculum, awareness raising, training for students and faculty, graduate-level and interdisciplinary research, a focus on specific national health problems, the establishment of a credit transfer system and recruitment of faculty with expertise, especially with a BME background. Adoption of these recommendations would boost training, research, resources, and facilities and in turn enhance public health and economic development.

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