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Review

Bridging the Gap: Evaluating Biomedical Engineering Internship Structures in Sudan and Globally

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ABSTRACT

This study presents a comparative analysis of internship structures within undergraduate Biomedical Engineering (BME) programs in Sudanese and international universities. A total of 51 programs were examined 9 from Sudan and 42 from institutions in Asia, Europe, Africa, and North America using content analysis of official curriculum documents. The investigation focused on key parameters, including internship type, duration, semester of implementation, credit hour allocation, training location, student evaluation methods, and the scope of skills acquired. Statistical analysis was conducted using Statistical Package for the Social Sciences (SPSS), with mode values employed to identify the prevailing trends. Findings reveal that Sudanese internships are predominantly mandatory semester-long placements focused on technical and operational roles, primarily within hospital settings. In contrast, global programs offer a more diverse range of internship types, including industrial, research, and summer placements, implemented across a wider range of academic semesters. These programs also offer more durations that are flexible, a broader range of credit hour allocations, and multifaceted evaluation methods that incorporate presentations, reports, and integrated assessments. Furthermore, international internships expose students to a wider array of professional domains, such as product development, manufacturing, regulatory affairs, and quality assurance. The study identifies significant gaps in the scope, flexibility, and alignment of Sudanese internship programs with global best practices. It recommends curricular reforms that emphasize industry collaboration, diverse training environments, and comprehensive evaluation frameworks. These enhancements are essential to strengthen the practical competencies of graduates, improve their employability, and align BME education in Sudan with international standards and evolving demands of the healthcare industry.

Keywords—*Biomedical engineering education, Internship programs, Curriculum development.*

INTRODUCTION

Biomedical engineering (BME) education encompasses both acquisition of theoretical knowledge and the cultivation of practical skills. While academic instruction imparts fundamental principles, experiential training, particularly through structured internships[1], is critical for developing the competencies necessary for professional practice. This investigation explores the disparities and commonalities in BME undergraduate internship programs between Sudanese universities and global institutions.

Context and Rationale for Comparative Internship Analysis

The global landscape of BME education is dynamic, responding to evolving technological and healthcare demands. Curricular development often reflects national industrial capacities, healthcare infrastructure, and accreditation standards.[2] Understanding the current state of internship programs in different regions, particularly comparing the emerging economies, such as Sudan, with more established educational systems, offers valuable insights into pedagogical approaches and practical training methodologies. [3] Such a comparative lens helps to identify areas for enhancement in preparing graduates for the biomedical sector.

Scope and Objectives of the Study

This study gathered data from the curricula of 51 universities: 9 Sudanese institutions and 42 global universities sourced from four distinct regions. These included 16 universities from Asia, 15 from Europe, 13 from Africa, and 7 from North America. The objective is centered on comparing internship programs for BME undergraduates based on a predefined framework. Key parameters examined included the type of internship, its duration, the number of semesters allocated, credit hour allocation, student evaluation instruments, training locations, student eligibility criteria, and the nature of skills acquired during the internship. Data analysis utilized Statistical Package for the Social Sciences (SPSS; IBM®, Armonk, NY, USA) employing mode statistics to discern the prevailing patterns.

Significance of Biomedical Engineering Education and Workforce Development

The comparative analysis holds substantial importance for advancing BME education, especially in Sudan. Identifying gaps and strengths in the current internship models[4] can guide curriculum reforms, ensuring that graduates possess relevant skills for the medical technology sector. Effective practical training translates directly into a more competent workforce, capable of contributing to healthcare maintenance, device development, and research. The findings may inform policydecisions aimed at fostering collaboration between academia, industry, and healthcare providers, ultimately bolstering national capacity in biomedical innovation and service.[5]

METHODOLOGY: DATA COLLECTION AND COMPARATIVE ANALYTICAL FRAMEWORK

This study utilized comparative content analysis to examine undergraduate BME internship programs. In all, 51 universities were selected, comprising 9 from Sudan and 42 from international institutions across Asia (16), Europe (15), Africa (13), and North America (7). The sample was chosen to reflect a range of educational systems, economic contexts, and accreditation standards.

Data was collected primarily from official curriculum documents and publicly available program descriptions. Key variables were extracted systematically, including the following:

- Duration of study: 3 years, 4 years, 5 years;
- Type of internship: industrial, field, research, summer;
- Duration of internship: 1 month, 2 months, 6 months, or 1 year;
- Semester of internship: three, four, five, six, seven, eight, nine, ten, summer;
- Credit hours of internship: 1 credit hour, 2 credit hours, 3 credit hours, 4 credit hours, 6 credit hours, 12 credit hours, or no credit hour;
- Place of internship: hospital, company, maintenance workshop within the university, or research foundation;
- Student evaluation of internship: report, presentation, examination, or all;
- Requirement of internship: optional during any semester, compulsory during the semester, after submitting a request;

• Experience during internship: technical, research, product development, manufacturing, quality assurance, validation, operations, or regulatory affairs.

Quantitative analysis was conducted using SPSS, with mode statistics employed to identify the most prevalent features across categories.[4] This facilitated the recognition of dominant patterns and institutional practices. Comparative metrics were developed to evaluate similarities and disparities between Sudanese and international programs. The methodology provided a structured, evidence-based assessment of internship design, supporting informed recommendations for curriculum enhancement and alignment with global BME standards.[6]

RESULTS

This section presents the findings of a comparative analysis of internship structures in undergraduate BME programs from 51 universities: 9 based in Sudan and 42 from various international regions (Asia, Europe, Africa, and North America). The results highlight differences and similarities in internship duration, type, scheduling, credit hours, evaluation, training settings, and the competencies acquired. Quantitative data were analyzed using SPSS, with mode statistics used to identify dominant patterns. The following subsections provide details of these findings, accompanied by corresponding figures that illustrate the distribution of key parameters.

Study Duration Distribution

Figure 1 illustrates the distribution of study duration across the surveyed BME undergraduate programs. The data indicate that the 4-year model is the most prevalent one, adopted by 56.9% of institutions globally. This format typically balances foundational engineering education with domain-specific biomedical training and is commonly implemented in North America and several Asian countries. In contrast, 31.4% of programs span 5 years, often incorporating extended industrial placements or intensive research components, a model frequently observed in parts of Europe and Africa. Only 11.8% of the sampled curricula offer a 3-year program, primarily within European universities that follow the Bologna Process, which separates undergraduate and graduate education more distinctly. The variation in duration reflects both regional accreditation standards and differing educational philosophies regarding the depth and breadth of training required for BME professionals.

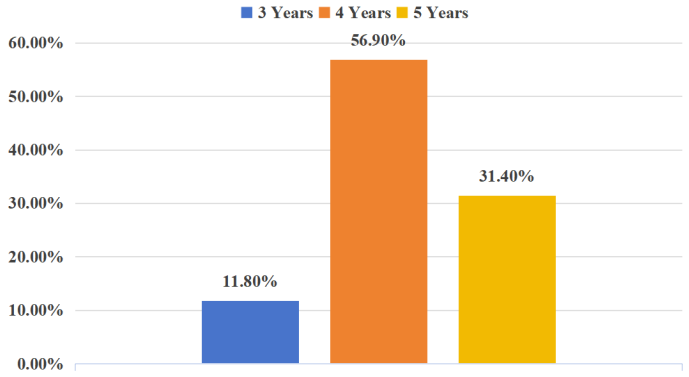

FIGURE 1. Study duration distribution.

Types of Internships

Figure 2 compares the distribution of internship types in BME undergraduate programs between Sudan and international universities. The data revealed clear contrasts in educational approaches.

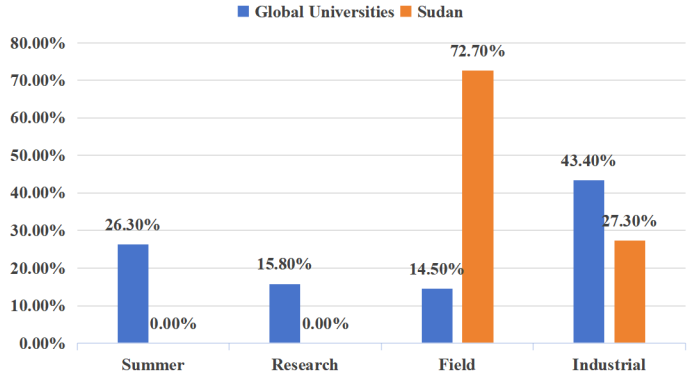

FIGURE 2. Types of internships.

Globally, universities implement a diverse internship model, including summer (26.3%), research (15.8%), field (14.5%), and industrial internships (43.4%). This variety provides students with a balance of academic, clinical, and industry exposure, reflecting a comprehensive strategy for professional development.

In contrast, Sudanese programs focus heavily on field internships (72.7%), primarily in clinical settings. Industrial internships account for 27.3%, while summer and research internships are absent. This narrow structure emphasizes

practical experience but may overlook research skills and innovation capacity.

The disparity reflects differences in institutional priorities and collaboration with research or industrial sectors. Enhancing internship diversity in Sudan could promote broader competencies and align training outcomes with global standards in BME education.

Duration of Internship

Figure 3 illustrates the duration of internships in BME undergraduate programs across Sudan and global institutions. The results reveal significant differences in internship structuring.

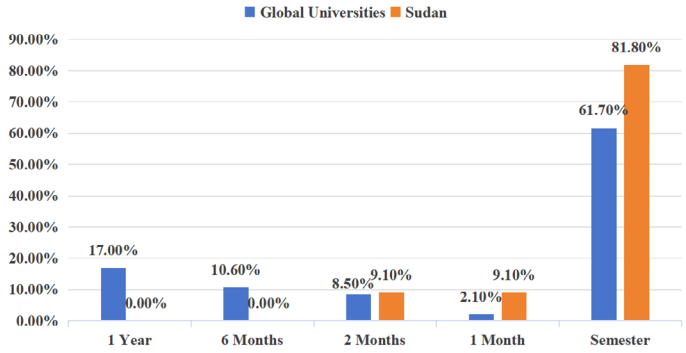

FIGURE 3. Duration of internship.

In Sudan, the majority of internships last for a semester (81.8%), with only 9.1% each for 1-month and 2-month durations. Notably, no programs in Sudan offer 6-month or 1-year internships, indicating a preference for medium-term academic placements aligned with university schedules.

Conversely, international programs demonstrate greater variation. While 61.7% also offer semester-long internships, a significant number provide longer durations, including 6 months (10.6%) and 1 year (17.0%). Shorter internships of 1 month (2.1%) and 2 months (8.5%) are also present, offering flexibility for students seeking condensed experiences.

These differences reflect contrasting educational strategies. Sudanese institutions prioritize structured academic integration, while international models emphasize extended professional exposure and flexibility, suggesting opportunities for curriculum enhancement through diversified internship timelines.

Semester of Internship

Figure 4 compares the timings of internships across semesters in BME undergraduate programs in Sudan and global universities. The data revealed notable contrasts in curricular planning and internship integration.

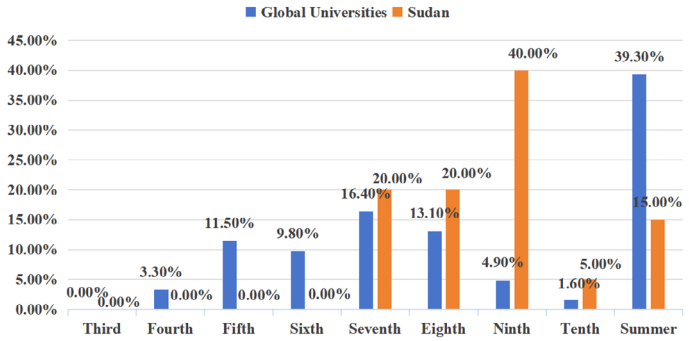

FIGURE 4. Semester of internship.

In Sudan, internships are concentrated in the later academic stages, particularly during the Ninth semester (40%), followed by the Eighth (20%), Seventh (20%), and Tenth (5%) Semesters. This pattern suggests a deliberate alignment with advanced coursework and clinical readiness, prioritizing internship experiences near the end of the academic program.

In contrast, global universities offer internships across a broader timeline. A significant portion occurs during summer terms (39.3%), while others take place as early as the fourth (3.3%), fifth (11.5%), and sixth (9.8%) semesters. This flexible distribution enables earlier exposure to industry and research environments.

The data reflected differing educational strategies: Sudan emphasizes late-stage internships, while global models integrate internships throughout the academic journey to support continuous professional development.

Credit Hours of Internship

In Figure 5, the chart illustrates the distribution of credit hours assigned to internship programs in BME across Sudanese and global universities. In Sudan, period of internship is mostly concentrated at 4 and 6 credit hours, each accounting for 33.3% of programs, followed by a smaller proportion (16.7%) of 1 and 3 credit hours. Notably, no Sudanese program offers internships with 2, 12, or non-credit hours. In contrast, global universities display a broader range, with the highest representation

(30.6%) being non-credit internships, followed by 12 credit hours (12.2%), 6 and 3 credit hours (14.3% each), and smaller percentages across other categories. The data suggested that Sudanese institutions emphasize a more uniform and credit-bearing internship structure, whereas global universities adopt diverse approaches, including non-credit options. This disparity highlights a potential gap in flexibility and accreditation strategies, which may influence internship depth, duration, and integration into academic progression of BME education.

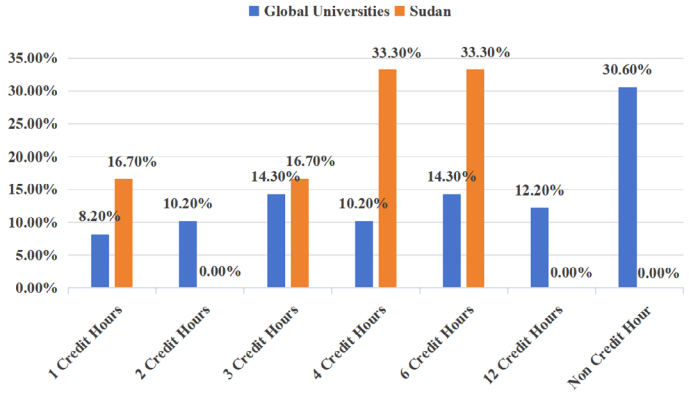

FIGURE 5. Credit hours of internship.

Place of Internship

In Figure 6, the chart compares the locations where BME internships are conducted in Sudanese and international universities. In Sudan, the most common setting is hospitals (39.1%), followed by companies (26.1%). Maintenance workshops at universities and research foundations each account for 17.4%. This distribution reflects the focus on clinical and technical maintenance training within Sudanese programs. In contrast, international universities demonstrate a more balanced distribution: companies lead with 38.8% internships, followed by research foundations (24.7%) and hospitals (25.9%). A smaller percentage (10.6%) conducts internships in university maintenance workshops. These findings suggest that Sudanese programs are more clinically and technically oriented, while global programs offer broader exposure, particularly in industrial and research environments. This may impact on the diversity of student competencies and the alignment of training with global BME trends.

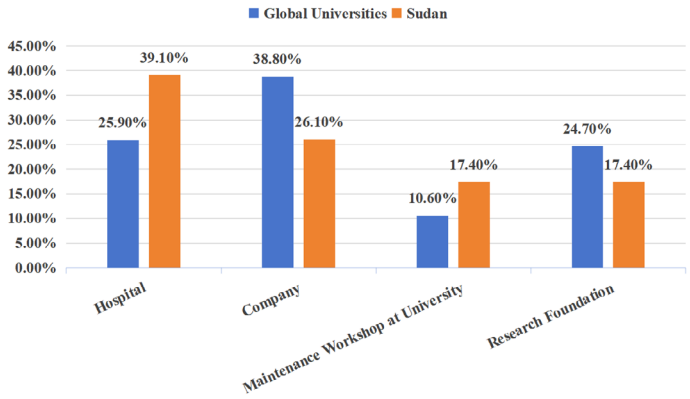

FIGURE 6. Place of internship.

Student Evaluation Internship

The chart in Figure 7 compares internship student evaluation methods in BME programs between Sudanese and global universities. It categorizes evaluation into four components: report, presentation, examination, and overall (all). In Sudan, the report is the most emphasized method (39.1%), followed by the presentation (26.1%) and examination (17.4%). In contrast, global universities prioritize the component of presentation (38.8%), with lower reliance on report (25.9%) and examination (10.6%). Notably, the "all" category—suggesting integrated or mixed evaluation approaches—is used more by global universities (24.7%) than by Sudanese institutions (17.4%). This indicates a global trend toward diversified evaluation methods, promoting comprehensive assessment through various performance indicators. Meanwhile, Sudanese programs show a stronger focus on written reports, potentially reflecting different academic cultures, resource availability, or institutional priorities. The comparison highlights the need for balanced evaluation strategies in Sudan to align more closely with global best practices, enhancing student outcomes and preparing graduates for interdisciplinary and practical challenges in BME fields.

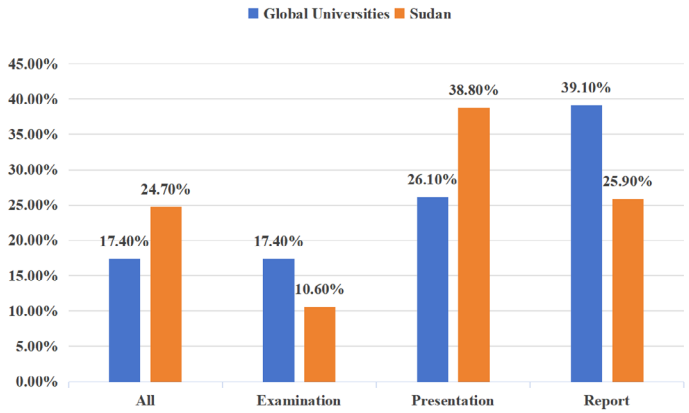

FIGURE 7. Student evaluation internship.

Requirements of Internship

The chart shown in Figure 8 illustrates the differences in internship requirements between BME programs in Sudan and global universities. In Sudan, internships are compulsory during the semester for 100% of the programs, showing a strict and standardized approach. In contrast, only 37.2% of global universities enforce this requirement, with more flexible alternatives in place. Globally, 48.8% of internships are available after submitting a request, and 14% are optional during any semester. This suggests that international programs provide students with more fulfilling internship experiences, possibly accommodating diverse schedules, student needs, or institutional structures.

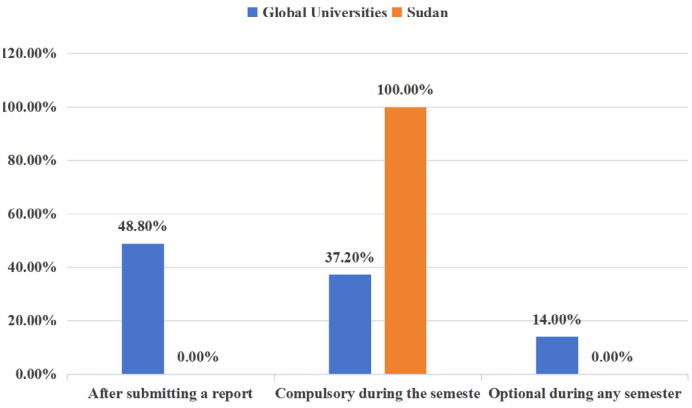

FIGURE 8. Requirements of internship.

The Sudanese model, while ensuring that all students undergo practical training, may limit flexibility and individual planning. In contrast, the global approach reflects a shift toward personalization and access-based learning opportunities. This comparison emphasizes the need for Sudanese programs to consider more flexible and student-oriented practical training.

Experience during Internship

In Figure 9, the chart presents the types of experiences BME students gain during internships in Sudan, compared to global universities. Sudanese students primarily receive training in technical (50%) and operational (50%) roles, with no exposure to other key domains. In contrast, global universities offer a diverse range of internship experiences, although at lower individual proportions. Globally, students engage in product development (16.4%), validation (14.2%), manufacturing (13.8%), quality assurance (13.4%), research (11.6%), and regulatory affairs (5.6%)—indicating a broader and more integrated training model.

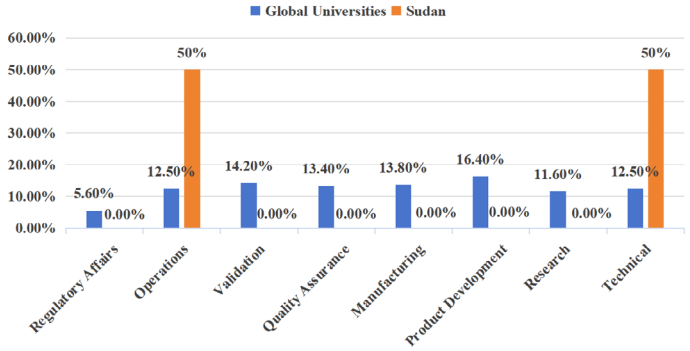

FIGURE 9. Experience during internship.

This comparison highlights a significant gap in the scope and variety of internship opportunities in Sudan. While the technical and operational focus provides practical grounding, the absence of exposure to innovation, compliance, and quality systems may limit readiness of graduates for the full spectrum of BME roles. To align with global trends, Sudanese programs should consider expanding internship partnerships and diversifying training environments across the biomedical product lifecycle.

CONCLUSION

Synthesis of Key Findings: Sudanese versus International University Practices

This comparative analysis of BME undergraduate internship programs reveals distinct differences between Sudanese and international practices. Sudanese programs

are characterized by a strong emphasis on field-based internships (72.7%), primarily conducted in hospital environments. These placements are uniformly compulsory and typically span one academic semester, with a primary focus on developing technical and operational competencies (50%). Evaluation methods rely predominantly on written reports and presentations.

In contrast, international programs demonstrate a broader and more diversified approach. Industrial internships (43.4%) and research-based experiences (24.7%) are more common, offering students exposure to a wider spectrum of professional domains, including product development, validation, quality assurance, and regulatory affairs. These global internships exhibit greater flexibility in structure and timing—ranging from short summer placements to extended 6- or 12-month programs—and often include elective or application-based formats. Furthermore, international institutions employ more comprehensive evaluation strategies, incorporating mixed methods to assess student performance.

Recommendations for Policy, Curriculum Development, and Future Research

In order to enhance the quality and relevance of BME internships in Sudan, several strategic recommendations are proposed:

Policy initiatives: Policymakers should prioritize the development of local medical technology manufacturing and research sectors. Strengthening these industries would create more diverse and high-impact internship opportunities beyond hospital-based training.

Curriculum reform: Academic institutions should broaden the scope of internship types by integrating structured industrial and research components into the existing curricula. Extending the duration of internships and awarding academic credits for a wider range of practical experiences can support more robust skill development.

Industry collaboration: Universities should actively cultivate partnerships with emerging biomedical technology companies in Sudan to provide students with hands-on experience in product design, quality management, and regulatory processes.

Future research: Further studies are recommended to investigate the long-term career outcomes of graduates from different internship models. Such research could evaluate the correlation between internship characteristics and professional success across diverse healthcare and biomedical sectors.

By implementing these recommendations, Sudanese BME programs can better align with global standards, enhance student preparedness, and contribute meaningfully to the national and international biomedical workforce.

AUTHOR CONTRIBUTIONS

Conceptualization, M.E.; Methodology, M.E.; Formal Analysis, M.E.; Investigation, M.E.; Data Curation, M.E.; Writing—Original Draft Preparation, M.E.; Writing—Review & Editing, M.E.; Visualization, M.E.; Supervision, M.E.; Project Administration, M.E.

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DATA AVAILABILITY STATEMENT

The documents and materials supporting the information presented in the Appendix: Biomedical Engineering Student Internship are available in the publicly accessible Google document at:

https://docs.google.com/document/d/1zuGCIOjfoFK68IP2bzSFOm0RZAihT7hucDfDgT8oelU/edit?usp=sharing. No additional datasets were generated in the course of preparing this appendix.

CONFLICTS OF INTEREST

The authors declare they have no competing interests.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable. The appendix does not involve human participants, animals, or primary human cell lines.

CONSENT FOR PUBLICATION

Not applicable. The appendix does not contain human participant data or identifiable images.

FURTHER DISCLOSURE

Not applicable. The content of this appendix has not been presented at any conference, uploaded to a preprint server, or previously published.

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