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Challenges, Strategies and Recommendations for Reengineering Engineering Education in Sub-Saharan Africa: A Review

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Abstract

With the continent of Africa occupying the front seat of underdevelopment in the world, and its population increasing exponentially, there is an urgent need to come up with strategies to tackle the underdevelopment ravaging the continent and the demand posed by its constantly growing population. Engineering through appropriate engineering education is the answer to these challenges. In this review article, some of the challenges facing engineering education in sub-Saharan Africa such as responsiveness and relevance in the design of the undergraduate curriculum, shortage in the engineering capacity, etc. were studied. The factors that influence engineering education, in general, were also discussed and the strategies that are required for producing engineering graduates capable of taking up the challenges facing the 21st century engineers in the region were highlighted. Lastly, the review presents a guide for future engineering education and recommendations on how to re-engineer engineering education in sub-Saharan Africa to produce engineering graduates who are qualified technically and otherwise.

Keywords: *engineering education, sub-Saharan Africa, reengineering, professional, collaboration.*

1. Introduction

As a field of practice characterized by the acquisition and development of knowledge, the use of both scientific and technical knowledge to design, invent, develop, innovate and to have a better understanding of the principles behind machinery, systems, structures, and design processes, Engineering forms the focal point of the today's development Fomunyam [1].

Engineering has been defined in several ways by different educational scholars but worthy of mentioning is the definition by Tredgold in 1828 [2, 3], where he defined engineering as "the art of directing the enormous streams of power in nature for man's use and convenience". This definition was further buttressed by the American Society of Education by aligning their thought in defining engineering as a simple art of applying mathematical and scientific principles, judgement, experience, and common sense in solving the problems of humanity. Solving the problem of humanity is the major function of the definition since the sole aim of engineering is to make work convenient for man [1, 4]. Embedded in engineering are other disciplines such as science, technology, mathematics, and other knowledge-facilitating endeavours like design management etc.

Engineering education as a field cannot stand alone because it greatly depends on other fields to add credence to it as a field of study since it comes with various concepts found in other disciplines like mathematics, science and technology. With the way engineering programs in Africa are structured by the colonial masters, and the entire curricula and engineering system taken from the colonial masters, there is an urgent call for higher education in general and engineering education in

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particular, to be decolonized in Africa, especially in South Africa [5]. In spite of South Africa being the centre of engineering education in Africa due to the fair availability of important infrastructure needed for a comprehensive offering of engineering education as a discipline as compared to other African countries, there is a profuse shortage of engineers in Southern Africa country and the solution to this is the encouragement of engineering education [1, 6, 7].

In view of the above, engineering education in South Africa and the world, in general, must assume a new shape and pace in order for the engineers currently under training and those aspiring to take up the profession to be able to meet up with the ever-demanding fourth industrial revolution since this revolution is currently determining the paradigm of educational landscape and businesses.

This study identifies the challenges facing engineering education in sub-Saharan Africa and provides strategies and recommendations for addressing them. Background of the challenges and different approaches to solving them are discussed in each section and subsection. Finally, guides towards the reengineering of engineering education in region Africa are presented.

1.1. Challenges of engineering in sub-Saharan Africa

It is no more news that engineering practice globally is the bedrock of every society and its contribution to societal development cannot be overemphasized. History has shown that human life and culture have been greatly influenced by engineering education. A long dive into the earlier days of engineering activities like the 2 500 BC, the era of the Egyptian pyramids, 500 BC in China, the bronze sword of King Goujians, the Dujiangyan water system in 300 BC in China and the Great Wall of China in 206 BC were some of the groundbreaking achievements in the history of science that pave way for the early engineering development. During these eras, experience and intelligence helped in the success recorded but in today's world, modern engineering leverages science and technology. Globally, universities, polytechnics, monotechnics and technical colleges are recognised as the place where vital engineering skills needed for technological, societal and economic development in any country are acquired, and the importance of engineering education in societal development makes it a must in any society aspiring for development.

The constantly increasing conduct of global activities, the huge need for infrastructural developments, the urgent need to better approach engineering problems and the unending need to face the current realities of our time attest to the relevance of engineering. In support of this, the Royal Academy of Engineering, RAE ascribed engineering capacity as being a focal point in the social and economic development of any nation Matthews, et al. [8]. Due to the role of engineering in all processes, tremendous improvement in all spheres can be attained if the tenets of engineering are adhered to. With Africa taking the front seat in all indices of underdevelopment, there is an urgent need for efforts to be doubled to advance the conduct of engineering education in the continent, and one of the ways this can be achieved is through the encouragement of the transfer of technology from developed countries without forgetting the importance of local content.

According to Winberg, et al. [9], the available pool of literature for engineering programs appears to be cumbersome for both the students and their tutors. This results in a high rate of attrition, poor performance among students, and a lack of diversity in the parts of the learners and teachers. Hence, there is a dire need for a complete overhaul of the program. Tremendous effort has been geared over the years towards changing this narrative by the government through investment in engineering education, targeted at improving the quality, quantity and diversity of engineering graduates. Yet, this body of knowledge still appears to be difficult for both the students and their tutors. In support of this notion, King [10] and Stiwne and Jungert [11] in their studies reported engineering programs as being difficult. However, no particular basis was given for their argument in spite of the noble profession being in existence for a long time. The difficulty of the program was ascribed to the reason why females shy away from it and the program only has more patronage from the males. In support of his notion, Matthews, et al. [8] reported in their study on engineering education in Sub-Saharan Africa that the role of engineering in social and economic development is crucial. They further stated that there is a serious shortage of engineers in the country which consequently results in the lower number of engineering graduates needed to meet the vast challenges in Sub-Saharan African countries.

Although South Africa poses a better engineering resource as compared to other African countries in the Sub-Sahara, they are still faced with a shortage in their engineering capacity. Research conducted by Lawless in 2005 attributed the shortage in the engineering capacity in the country to the high rate of emigration of already established engineers to other countries in search of greener pastures and better opportunities [1]. Hence, the country is deprived of the capable hands needed to advance the course of engineering and improve the economy. As part of the survey conducted by Lawless in Sub-Saharan Africa [2], about 40 % of professional engineers in the region strongly believe that the necessary skills needed by graduates cannot be delivered through engineering education. Based on this, Shay [12] ascribed one of the major challenges bedevilling engineering education to a lack of responsiveness and relevance in the design of the undergraduate curriculum. This notion was further supported in 2017 by Fomunyam [5] and Chen, et al. [13] who emphatically stated that the bedrock of all learning experiences is a good curriculum. As such, a good curriculum must be designed to incorporate all the relevant skills needed to produce graduates that will be of relevance to society. Hence, a good curriculum must be flexible enough to capture the current realities as what was obtainable in the past might be obsolete now. Based on this notion, Shay [12] suggested that every curriculum must be relevant to current reality and should be designed to meet the needs of the learners or students. Since society and the labour market are constantly changing, there is a dire need for the graduates produced to possess the skills that match the constantly changing role that is required of them. These skills cannot be produced when the students are taught using an inadequate curriculum. Based on the fact that engineering has more to do with professionalism, engineering practice must be tailored to meet local needs more than just accepting the Western approach hook, line and sinker.

According to Garuba [14], the worldviews have subjugated the South African higher education landscape. This singular act he claimed is preventing local experiences and indigenous knowledge from seeing the light of the day. In general, he noted that the views of the Western world are upheld above indigenous experience thus, preventing the use of curriculum to epitomize the accepted cultural values, perspectives and experiences of South Africa. Hence, deficiency in the curriculum used over time is attributed to the shortage in the supply of capable engineers, as students produced using the deficient curriculum lack the vital content of engineering education and thus, end up exiting the university with poor qualifications and skills [5] because they are unable to make meaning out of the contents they were exposed to and will eventually develop little or no relevant skills prior to their graduation [15].

The finding by Greve [16] shows that within the first two years of admission into the university, a good number of engineering students often drop out in South Africa. Also, racial and gender supremacy was observed to be very pronounced in the field of engineering and South Africa appears to be at the receiving end as the study conducted by the Engineering Council of South Africa (ECSA) [17] shows that 70 % of the 16 423 registered professional engineers are white and just 713 are female. The statistics show a great discrepancy in the distribution along gender lines and race, and tremendous effort must be geared towards balancing this wide deviation as current issues affecting gender and black South Africans might be the focus of the used curriculum. According to the study, if this discrepancy is not checked and addressed, it could result in a total disconnect between the general society and educational institutions.

In summary, **Figure 1** depicts some of the general challenges of engineering education within and outside the sub-Saharan region of Africa.

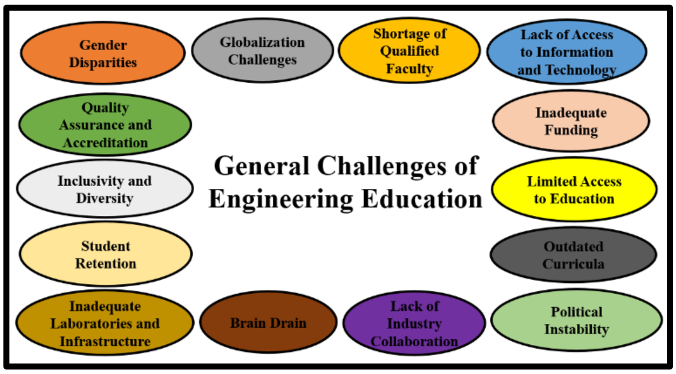

Figure 1. General challenges of engineering education [18].

1.2. Future of engineering education in sub-Saharan Africa

There is no doubt that the future of engineering education in Africa will be greatly influenced by the general economic trend, rapid technological development, and environmental and health challenges [15]. As such, the various technologies with the potential to impact industries must be incorporated into engineering education in sub-Saharan Africa. A good example is digitalization, a product of engineering education which over the years has led to the creation of more jobs. Buttressing this notion is the findings in 2017 by McKinsey Global Institute which showed that an estimated 3.5 million jobs were lost in the United States of America due to the advent of personal computers in the 1980s. However, it was estimated that about 19 million new jobs were created due to the new technology [19]. There is no doubt that the introduction of new technologies will disrupt the current norm and old jobs will be replaced with new ones, and digitization alone can create 1.8 million new jobs due to improvements in the modes of production [19].

2. Factors that Influence Engineering Education in sub-Saharan Africa

Depicted in Figure 2 are the factors that influence engineering education in sub-Saharan Africa. Each of these factors is enumerated in the subsequent subsections.

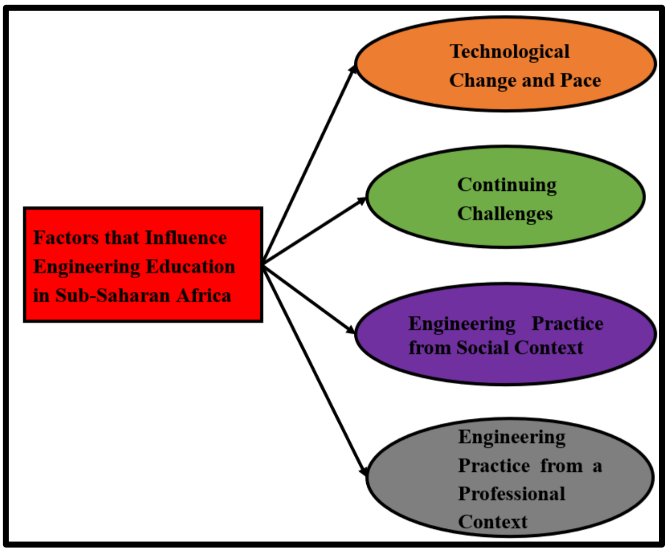

Figure 2. Factors influencing engineering education in sub-Saharan Africa.

2.1. Technological change and pace

Change is a constant phenomenon and in reality, the past 100 years have experienced more change than the preceding years such that at the end of the 20th century, the developed world posed of safer, healthier and more productive space where engineering through the advancement of technology had made an irreversible imprint in lives of the people and the society at large [20]. According to Wright in 1999, scientific and engineering advancement doubled every 10 years and this geometric growth has resulted in a high rate of introduction and adoption of technology [21]. Based on this, there is a drastic and continuous decrease in the production cycle time and often, each new cycle adopted delivers a more functional and less expensive version of the manufactured products [22]. Thus, older technologies are fast becoming obsolete and recent or emergent technologies such as nanotechnology, biotechnology, material science and photonic and other unanticipated technologies will take the world by storm and be among the changes needed by engineering and engineering education in order to contend in the 21st century and beyond [23-25].

2.2. Continuing challenges

The 21st-century engineers in sub-Saharan Africa need to acquire new technical skills and information in order to be on par with the rest of the developed world. There is no doubt that some old problems will linger for a long time and thus will demand special attention and perhaps, new technology will be the only way out as neglecting them could lead to a more serious crisis [26]. In the developed world, the United States of America arguably had the best infrastructure. Sadly, these infrastructures are experiencing a serious decline, and due to the recent vintage, infrastructures like information and telecommunications suffered less degradation [27]. However, infrastructural vulnerabilities resulting from accidents or intentional events are a major concern. Nevertheless, natural resource and environmental issues will continue to structure the challenges of the world, and sub-Saharan Africa is not an exception. A typical example is an estimated 40% increase in electricity, 20% increase in natural gas energy and 40% increase in gasoline needed in the state of California in the year 2020 as compared to what was needed in the year 2000 [28].

Furthermore, it is estimated that by the year 2025, about 2.8 billion people from 48 countries could face freshwater shortages [29]. Also, a good population of people in countries of the world and sub-Saharan Africa, in particular, will age and the onus is on engineers in this region through appropriate engineering education to develop assistive technologies for the aged citizen to help maintain their health and productive lifestyle beyond the conventional retirement age.

2.3. Engineering practice from social context

It is crystal clear that we live in a society with an uncertain future, nevertheless, it is obvious that engineering cannot operate in isolation or better still in a vacuum in the 21st century anymore [24], being on a macroscale where the natural resource of the world is stretched due to the constantly growing population or on a microscale where engineers are required to have a good understanding of the effectiveness of teamwork and the importance of social issues to engineering. It was estimated that the world population will hit about 8 billion by 2020 with the majority of the increase found amongst the developing and underdeveloped nations [30]. Hence, it is of urgent importance for the engineering profession especially in sub-Saharan Africa, through proper engineering education to come up with solutions that take care of the increasing population in the region by drawing more students from other sectors not well represented in the engineering workforce[31, 32].

With the advancement in health and healthcare knowledge, there is an appreciable positive shift in life expectance. Hence, there is an increase in the number of healthy people living beyond retirement age and fewer young and able workforce available to pay for the services expected of the ageing population. Hence, 21st-century engineers are expected to operate in such an environment and must be compelled to do so due to its necessity [32]. It was estimated that by the year 2020, politically unstable nations of the world would experience disproportionate youth between ages 15 to 29 years as more than 50% of the population of the world could fall below 18 years resulting in a youth bulge. This could likely lead to serious social and political tension due to excess idleness amongst the youths who are unable to be gainfully employed. Thus, the world could be faced with unending political and social unrest such as kidnapping, terrorism etc. as currently experienced in some parts of the world. Consequently, there would be an increase in demand for military service with all necessary security measures in place both domestically and abroad. In the face of this unrest, the economy of the world which is tightly interlinked would remain so with a shortage of economic and military warfare. With all these happening, engineering services incorporated via engineering education would be worldwide, as jobs would be made to move freely, and information sharing would be allowed via the internet which utilizes high-speed computers [33].

2.4. Engineering pPractice from a professional context

In recent times, the gradual increase in knowledge within the field of engineering led to new subspecialties such as photonics, biomechanicals, microelectronics etc within the field. Nevertheless, simple challenges from biomedical devices to more complex challenges faced during the manufacturing and design of giant network devices require a perspective that encourages multidisciplinary collaborations with teams of technical experts [34-36]. This team of experts must possess important attributes such as excellent communication skills with members of the team and the public audience, communication using available technology, and must also have an in-depth understanding of the global market and social context. In addition, the team should be flexible in their dealings by being ready to embrace positive changes [37].

The advancement in technology and the ease of knowledge sharing will make it possible for the actualization of new-era customization that possesses a buyer-centric strategy that aids mass customization with a customized market [38] that will allow social interaction between customers and engineers more than we currently have today. As a result of this, engineers would not only develop their technical ability in problem-solving but also their interpersonal communication skills [39].

Since military strength, business competitiveness, the standard of living and the health of every nation are directly or indirectly tied to engineering, the ingrain of technology in every facet of our lives is on the increase due to the increase in the convergence between public policy and engineering. This synergy requires engineers to develop a technique on how to make both technology and public policy interact for effective results as there is still limited engagement of engineers in public issues at present. Consequently, it is very crucial for engineers in the world and sub-Saharan Africa, in particular, to protect the image of the profession by articulating their relevance to many public policy issues. This can be achieved by enlightening the public on the role of engineering so that the value and consequences of the profession can be appreciated.

Proper attention must be paid to ethical engineering issues through case study reviews that are supported by advances in technological information in order to avoid repeating past mistakes and create a platform to embark on best engineering practices.

3. Strategies for the 21st Century Engineers in sub-Saharan Africa

In this century, the pursuit of effective engineering education should be done within the context of a comprehensive evaluation of all aspects relevant to all the interrelated systems of engineering education, the global economic system, engineering practice and the K-12 or high school feeder system. As a rule of thumb, the realignment of engineering education is needed in order to promote the attainment of the characteristics required of a practising engineer [40]. This can be achieved through a continuous and increased emphasis on the conduct of research-based engineering practice and education fully supported by stakeholders like engineering professional societies and engineering faculty.

3.1. Comprehensive effort engagement

In recent times, efforts geared toward reform have been targeted at a single element of a complex and interconnected system [41]. This approach is believed to be inappropriate as the entire systems need to be considered even if a narrower focus is taken at the end. Based on the professional engineering practice context, a system that incorporates at least one of these elements must be considered:

1. The use of engineering processes in the definition and solving of problems based on scientific, professional and technical knowledge.
2. The use of a team consisting of engineers and professionals from diverse fields of study or discipline in problem-solving processes.
3. Employ engineering tools and tools used by other professionals in problem-solving.
4. Setting a common goal between engineers, customers and engineering managers via active interaction.
5. Political, economical, social and ethical constraints should be set as the boundary conditions that define the range of possible solutions to engineering problems and possible interaction between engineers and the public.

In line with the above-mentioned elements that need to be incorporated into a system, one must also consider other engineering education system elements such as:

1. Teaching, learning and assessment processes that transform learners from one form of acquired knowledge and professional preparation to another.
2. The primary actors in the process of learning should be the students and teachers.
3. Laboratories, standard curricula, instructional technologies and other materials or tools that aid teaching and learning should be incorporated..
4. The general goals and objectives of engineering education as related to the institution, department employer, and relevant stakeholders etc. must be considered.
5. The external environment such as the technological process and business cycle that determine the entire shape and demand for engineering education should be considered.
6. A flexible process that allows for goal and objective revising when there is technological advancement or a need for urgent change must be incorporated.

Reengineering being the major goal of engineering education in sub-Saharan Africa must focus less on enterprise organization and more on its product and services, also known as the outcome. In order to re-engineer engineering education in sub-Saharan Africa, questions like "How can we improve our processes for more efficient output, quality, simpler, more flexible and less expensive product"? must be asked. It starts by first identifying the outcome, service or product desired and then, embarking on backward design, bearing in mind what the outcome must look like and the processes that must be used to produce it. Since both, the product and process are used to determine the quality; an enhanced educational experience designed for engineering students with an opportunity to pursue engineering as just a liberal education must be made available.

3.2. Linkage consideration

By nature, engineering practice is generally characterised by limited contact with the public. This is due to the required credentials for practising engineering, the rigour, the structure of engineering education and other baccalaureate. All these factors account for the public perception of the status of engineers and the engineering profession at large [42]. If changes are to be thought of in engineering, proper attention must be paid to system optimization that leads to an improvement in the profession's stature. Just like science whose origin was ascribed to the work of scholars who received support from wealthy patrons, engineering originated from trades and attempts to develop and implement something useful for military purposes at first and civilization purposes in the later stage. In the past, artefacts were created for the armouries by the craftsmen in the military or for the public by tradesmen. This knowledge was passed from one generation to another through an apprenticeship system. Today, most of the artefacts produced are more complex than what a mere tradesman can produce as these new artefacts require engineers to design and produce them. The apprentice system used in the early days is now been replaced by formal engineering education that is based on engineering practice. Also, there is a paradigm shift in the basis of engineering education from the fundamentals of science and mathematics used in the mid-20th century due to the constantly increasing complexity of engineering problems.

Over time, there has been a serious disconnect between practising engineers and academic engineers as most of the engineering faculties are without industrial experience [43]. This has been the reason spotted by industrial representatives as a major cause for turning out engineering students who are not sufficiently prepared to face the challenges facing engineering today. Worthy of mentioning is the fact that engineering education has been designed to span for four to five years after which the students become engineers. This approach took precedence from the origin of apprenticeship, where the training process was designed for graduates to be gainfully employed upon graduation into the industries as soon as possible. Sadly, this approach has been recognised by other professions as inadequate. The comparison of the engineering profession with other professions is depicted in **Figure 3.** From 2010 till date, the years of formal education required to start practising in different fields have not changed significantly [44, 45].

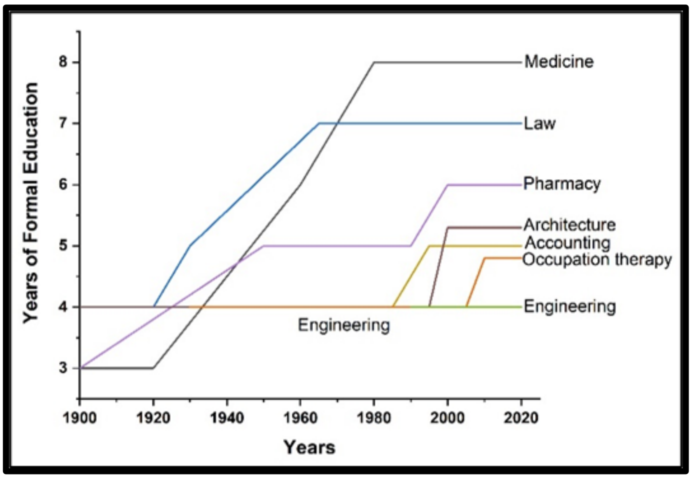

Figure 3. Total number of years of postsecondary education needed to start practising in different fields [2, 46].

From the comparison of the educational practice of other professions shown in Figure 1, there is a perception that at least 2 years of education are required after the baccalaureate or bachelor of engineering degree for one to become a professional. No wonder, engineers do not command as much respect in the eye of the public as other professions like medicine. Hence, this problem is being addressed by engineering societies worldwide through the creation of examination bodies that award a license to professional engineers after passing certain examinations of such bodies.

To improve the quality of engineers produced, professional societies and engineering schools need to come up with other ways to repackage engineering education such that it will command the appropriate respect in the eyes of all. As a possible way to promote the needed recognition and credibility, both the professional societies and schools should adopt a master's degree as a professional degree since this degree would clearly provide market value if a large number of engineers are willing to invest the required time and money to acquire it.

3.3. Concentrate on levers for change

The fact that the trans-organisational character posed by the engineering profession is one of the factors bedevilling engineering education and engineering practice at large. Practising engineers tend to maintain a professional identity irrespective of who their employer is. Being a member and adhering to the ethics and professional code of conduct of the society makes it possible for this to be achieved since the professional society is known as the main avenue through which engineers can support their professional identities, identify opportunities related to their profession and communicate collectively on issues affecting the profession with respect to policymaking [47, 48]. Being a vital avenue through which knowledge is passed to the members, professional society plays a very crucial role in correctly advising both the members and the public on the changes in the engineering education system [49], and engineering faculty are expected to be at the front line as regard any information on new changes and also give their maximum support in engineering innovation. It is obvious that providing incentives to support engineering innovation is sort of difficult due to the current reward system of the faculty that is based on excellent research. Of course, most nations have benefited tremendously from university research conducted at the doctoral level but this is yet to translate into success at the undergraduate level, especially in sub-Saharan Africa.

A study conducted in 1998 by Adelman [2] shows that 98% of undergraduate students switched to other major forms of engineering and the major reason for their decision was attributed to poor teaching while 81% of the undergraduates cited inadequate advice as to their reason for switching [50]. Hence, more attention needs to be paid to effective teaching, learning and monitoring of students in order to enrich the undergraduate experience of students in sub-Saharan Africa. This change can only be brought about by critically engaging leaders of the faculty like the heads of departments, deans and students on how to come up with a model that rewards excellence amongst deserving students since they are the key players in the engineering education system and are seeking to prepare for the professional task ahead.

Alongside engaging direct levers, the impact of 21st-century engineers' initiatives will be dependent on how the perspectives, energy and imagination of the broader spectrum of persons can help in designing, implementing and the assessment of systematic changes that are required to create an engineering enterprise that will efficiently serve the societal interest. To achieve these, the young known as the rising engineering leaders, those in charge of career development in government and industries, practitioners from different disciplines, experts in learning theory and sciences, professionals from the field of communication etc. should be motivated to become engineers.

3.4. Focus on student-centered education

Maximum attention should be geared toward addressing the learning patterns of students and what they learn because the outcome of their learning must focus on performance and portray the characteristics required in future engineers [51, 52]. This focus is defined by two major tasks:

1. Proper alignment of engineering curriculum and academic experience with the opportunities and possible challenges graduates will encounter in the workplace.
2. Proper alignment of the skills set by the faculty with those required to efficiently deliver the curriculum desired in line with the diverse learning patterns of the students.

Having recognised these challenges, the engineering professional societies should leave no stone unturned in trying to create a synergy between anticipated future work requirements and academic experiences. Based on this, different engineering societies should reassess the bodies of knowledge expected of professionals in their diverse disciplines like civil [53], computer engineering [54], chemical engineering [55] and mechanical engineering [56]. In recent times, university faculty and professional engineering societies have come together to deliberate on ways to improve the effectiveness and quality of instruction and student learning techniques. In America for example, there is a collaboration among the American Society of Mechanical Engineers, American Society of Civil Engineers, Americal Institute of Chemical Engineers, and the Institute of Electrical and Electronics Engineers to offer “Excellence Engineering Education” through the organization of different workshops for engineering faculty.

3.5. Research base development

It has been observed that the structures and processes involved in educating, skills maintenance and employing science and engineering talent in any workforce are diverse as they have dynamic and complex interrelationships [57]. Due to this complexity, the modus operandi involved in turning out qualified scientists and engineers and having them gainfully employed into a suitable system is not well understood [58, 59]. According to Rosalyn Williams, the engineering education system is evolving and as a profession, it is undergoing a transformative evolution [60]. She noted that the fundamental engineering processes such as design, development etc. remain the same but the areas of application are expanding geometrically. Hence, an urgent need for the development of a better understanding of engineering practice models in this era of technological evolution [60].

The growth in the body of research at the level of learning for students can be adopted as a guide and check to determine the level of transformation achieved by the undergraduate in the learning environment. Previous efforts towards engineering education reformation being it an individual program or course on campuses have been motivated primarily by the experiences and opinions of those leading the struggles. A publication by the National Research Council (NRC) titled " How People Learn", shows the level of sentiment in the educational community [61]. The publication clearly outlined the progress made in understanding the theory of learning by researchers in the learning sciences. As a rule of thumb, the laid down rules should serve as a guide for engineering educators in conducting engineering research as these would help them to come up with designs that can address important issues related to expanding participation, creating courses for non-majors, improving and retaining majors, and creating an alternative degree for students interested careers other than the traditional engineering. By paying more attention to research and learning, we would have a better understanding of:

1. How to cater for students using diverse styles of learning.
2. Why pedagogies and specific approaches work.
3. How to assist students in clarifying, defining and confirming their career goals and prepare them for graduate school when necessary.
4. How to make them lifelong and responsible learners.
5. How to support students' learning using information and technology.
6. How the specific skills needed for their engineering practice in the 21st century can best be learnt.

3.6. Effective Communication

In order to realign engineering education in sub-Saharan Africa and the world at large, strategies that capture the context of the understanding of all the elements of engineering must be developed. The strategy must also recognise the relevance of constant communication on the goals and values of successful engineering education reinvention with the engineering community stakeholders and the public at large. Over the years, healthy communication has been established across engineering education establishments which comprise groups with a common interest. However, the same cannot be said about the communication between the public and engineering schools. In an effort to enhance the awareness of engineering to the public, the engineering community has adopted a vast approach such as making the public see the role of engineers in the actualization of an engineering system and the level of education required to be fit for such work [62, 63]. Nevertheless, this effort has yet to achieve the required success [62] as the public still has little understanding of the value and nature of engineering education, and how the constant societal change can make it an attractive option for their children. Therefore, as a key element, communication must be enhanced in every ramification in order to promote the systematic change needed in engineering education.

A pre-college survey conducted amongst students has shown that students consistently show greater interest in careers associated with helping others [64, 65]. As such, it would be helpful if the engineering community could effectively communicate the engineering social context, the numerous engineering contributions to the quality of life and the other social responsibilities of engineers other than just responsibly exercising their skills. In view of these, some authors suggested that engineering education should be altered to explicitly make the required connections [65-68]. An indication of the engineering community to communicate their message is depicted in Table 1.

Table 1. Professional careers perception of students [2, 64].

Professions	High opinion (%)		Careers % extra worth	
	High School Students	College Students	High School Students	College Students
Lawyers	45	38	71	77
Doctors	78	85	90	92
Engineers	**58**	**72**	**68**	**35**
Teachers	66	83	70	81
Accountants/CPA	30	36	40	47

From the table, only 35% of college students agreed to the fact that engineering as a career is worth the extra effort. It is disheartening to know that college students who are expected to be more knowledgeable about the nature of engineering have a lesser opinion about engineering than high school students but are less likely to agree that an engineering career is worth the extra effort.

The engineering community as a matter of great importance must communicate effectively in a society with constantly increasing technology about the value of engineering training for different tasks or challenges that are not considered within the traditional engineering boundaries [69]. Data from the National Science Foundation (NSF) in 1998 [70] shows that about 1 million people out of 2.2 million people with engineering degrees indicated that their main occupation is not engineering. Also, data collected by NFS and depicted in Figure 4 shows that engineering graduates who combine other non-science degrees with their engineering degrees are most likely to hold top positions in their careers at some point [70].

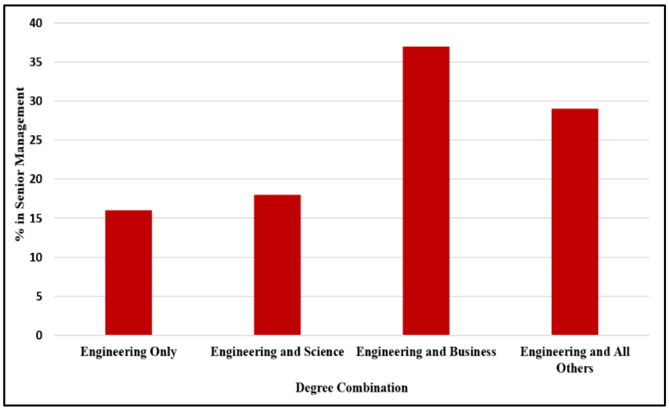

Figure 4. Likelihood of attaining a senior management level by a combination of another degree with an engineering graduate degree [2, 70].

Thus, the depth and breadth of engineering must be made obvious to the public as engineering education offers students the opportunity to expand their knowledge.

4. A Guide to the Future of Engineering Education in sub-Saharan Africa

Specific programs and several mechanisms have been investigated in an attempt to effect positive change in engineering education in particular and education in general. Some of these are discussed in subsequent sections.

4.1. Collaborations

Effecting positive changes in the educational sector has proven to be somewhat tedious as shown by the slow pace of success recorded in the past, particularly with engineering education. Nevertheless, some appreciable success has been made now as compared to what was obtainable in the past, especially in the attempt to transform engineering education [71]. There is a wider range of collaborations currently in place in most parts of the world as compared to what was obtainable in the past, with some of these collaborations being sponsored by federal government agencies like the National Science Foundation (NSF), industries, professional associations/foundations and global partners. The outcome of these collaborations has proven to be an effective means to develop the kind of relationship, be it formal or informal, needed for systematic change.

From collaborations, the collective process of goal setting, designing, implementation and the assessment of curricula and the use of technology for the enhancement of learning can be achieved. Furthermore, collaboration creates an avenue for one to learn how and how not to incorporate reforms and innovations in diverse settings, on campuses with diverse missions and circumstances [72]. The 21st-century engineers in the United States of America to be specific do not assume that there is a particular way to transform the learning environment, however, they believe that one should take advantage of the diversity of higher education. Adopting this approach in sub-Saharan Africa, engineering programs could be designed for specific areas of excellence that will serve regional industrial communities and infuse requirements into undergraduate learning space or environment by focusing on a specific area within engineering and pinpointing the development leaders for the engineering profession. At the local level, support is needed to adapt the work done by others. Thus, the leaders on campuses must be able to exercise profuse leadership that helps shape the lined-up agenda in such a way that it makes complete sense without losing the vision of the future. To achieve this, the right question needs to be asked at every stage of the process and the questions must be revisited based on the returned answers they proffer.

4.2. Technological collaboration

In addendum to the active collaboration experienced in the past, electronics technologies have made the sharing of materials, ideas and other resources that aid the transformation of individual courses, departments, laboratories, programs, or institutions [25]. A systematic approach must be adopted in information sharing in sub-Saharan Africa for proper integration, analysis and dissemination of data and the best practice must be applied at every stage of the course, curriculum and laboratory transformation.

4.3. Related efforts

To achieve the goals of reengineering undergraduate engineering in the 21st century in sub-Saharan Africa, there is a need to leverage individual experiences and institutions working tirelessly to transform the programs of undergraduates beyond science, technology, engineering and mathematics (STEM) [73]. Multidisciplinary collaboration within campus extends the opportunity for best practices sharing beyond the four walls of the community of engineering educators. STEM is currently dealing with the same pattern that redefines the learning environment of undergraduates. The approach adopted for this includes:

1. Creating awareness that portrays acquiring knowledge in science, mathematics, technology, and engineering during an undergraduate career as an ideal way for the preparation targeted at covering wider societal roles because the dependence on a nation's citizens with a solid scientific and technical understanding is on the increase [74].
2. Focus more energy towards education and research integration in order for all students to have access to discovery-based and problem-solving experiences during learning.
3. Boundaries dissolution between disciplines to encourage imagination, diversity and fast adaptation in both individuals and institutions. This does not only aid or facilitate research, but it also encourages the immediate and broader application of the results of the research as related to the environment.
4. Come up with interdisciplinary research questions and activities that are integrated to merge data, methods and ideas across temporal, spatial and societal scales [75].
5. Increase in the effort put into learning in the science community and that of researchers in specific disciplines saddled with the responsibility of exploring how people learn things that serve as the foundation for designing, implementing and assessing new methods or approaches that transform undergraduate education course by course, program by program and institution-wide level [76].
6. Encourage accountability through the application of external pressure which in turn aids greater stewardship over the quality and character of learning by allowing a clear definition of mission and educational goal, and working assiduously to meet the goals [77].
7. Development of demographics for students such that it portrays a profuse diversity from the

academic preparation perspectives, career aspirations, and ethnic background which makes teaching, learning, and research designed with an intent to celebrate this diversity.

8. Development of faculty demographics that show the anticipated retirement pattern. This makes it possible to prepare incoming faculty and also consider the required skills needed and the rewards and incentives that such scholarly effort put into acquiring such skills would attract.
9. The pressure to effectively use the available resources to serve the agreed priorities.
10. Leverage the opportunity new technology affords to transform the learning environment.

With the new and continuous development of sophisticated technology by universities, industries, research institutes, etc., and the promises made by the governments of different countries to transform every industry and human endeavours, there is every possibility that these new technologies would be harnessed to transform engineering education and training beyond our imagination [78, 79]. The fast technological advancement over the years has encouraged the usage of simulation, visualisations, game-playing immersive environments network learning, intelligent tutors and many more in the learning environments. Further advancement in technology in the coming years could compel learners to upgrade in order to meet all the requirements needed to boost learning productivity and lower its cost [80, 81].

5. Recommendations

5.1. Aspirations and attributes of the 21st century engineers

A set of aspirations was enunciated within the context of the constantly changing national and global landscape for engineers in the 21st century by an engineering committee set up in the United States of America. Based on these aspirations, a high but achievable standard was set and these standards are believed to be attainable if all the necessary causes of action are taken. At the core of the action needed to be taken to attain this standard is the need to have technically proficient engineers who have acquired not just quality education but also see themselves as global citizens capable of handling business and public service with sound ethics [82]. To achieve these aspirations, 21st-century graduates of engineering need certain attributes such as strong analytical skills, ingenuity, creativity, professionalism and leadership skills [83, 84]. It is believed that the implementation of the recommendations made in subsequent sections will allow the aspirations and desired attributes to be met.

5.2. Reengineering the engineering education system in sub-Saharan Africa

Based on the discussion from previous sections, it is obvious that a full-blown body of knowledge of science and engineering cannot be compressed or accommodated within the traditional context of 4-years bachelor's or baccalaureate degree. Knowing fully well that the main attribute of engineering graduates is technical excellence, the graduates also need to possess a level of communication, teamwork, ethical reasoning, societal and global contextual analysis skills with good work strategies understanding [85, 86]. Hence, neglecting development in these areas and acquiring skills and technical disciplinary subjects to the exclusion of economics, humanities, political science, and/or other technical interdisciplinary subjects is to the detriment of graduating engineers capable of communicating with the public and engaging effectively in the global engineering marketplace [24, 87]. Based on these, the following are recommended:

1. Recognition of baccalaureate degree in engineering as a pre-engineering degree

The difference between entry-level engineers and engineers who have mastered the engineering discipline through furthering formal education or self-study that is subjected to examination should be made obvious. Also, a broader view of engineering education that incorporates liberal engineering education in an educational establishment, and allows students who wish to use the course as a stepping stone to pursue other careers like medicine or law should be encouraged. Since it is impossible to become a specialized engineer upon acquiring a baccalaureate degree, it is paramount that the stature of the profession be promoted by allowing engineering schools to create accredited professional master’s degrees targeted at expanding and improving the skills of graduates and enhancing the performance of practising engineers.

2. Accreditation of engineering programs with the same name at the baccalaureate and graduate level in the same department to give credence to the fact that

education through a professional master's degree produces an accredited master's engineer (AME).

3. The flexibility of outcomes-based accreditation should be vigorously exploited by engineering schools in order to experiment with the already existing models for baccalaureate education.

4. Regardless of the creative approach adopted for the four-year engineering curriculum, the importance of engineering which includes the iterative design process, performance prediction, building and testing should be taught at the early stages of the curriculum.

5. The engineering education establishment such as the Engineering Dean Council should endorse research in engineering education as an activity that should be valued and rewarded by the engineering faculty as a means of enhancing and personalizing the connection to undergraduate students, to understand how students learn, and appreciate the teaching approaches that excite the student.

6. New standards should be developed by universities and colleges for faculty qualifications, appointments and the expected experience acquired by a practising engineer. To achieve these, developmental programs must be created or adapted to support the required professional growth of the engineering faculty.

7. In addition to content delivery engineering schools are known for, engineering students must be taught how to learn and play a continuing role with professional organizations to facilitate lifelong learning through the offering of a technical **executive** degree similar to executive MBAs.

8. Interdisciplinary learning should be introduced at the undergraduate level in engineering schools rather than at the executive level of the graduate program.

9. Case studies of success and failure in engineering should be developed by engineering educators and used appropriately in the design of undergraduate and graduate curricula.

10. The engineering school must ensure that they work with local community colleges to ensure seamless and effective articulation within two years of undergraduate programs.

11. Programs that encourage domestic engineering students to aspire for master's and PhD degrees must be encouraged by engineering schools.

12. Engineering schools should support the efforts of other bodies to improve mathematics, science and engineering education at the high school level or K-12 level (using US standards).

13. The engineering education establishment should corroborate the effort of the nation to promote the public understanding of engineering and technology literacy.

6. Conclusion

This review article focuses on engineering education in sub-Saharan Africa. The challenges, strategies and recommendations for reengineering engineering education in the region are presented. With Africa occupying the front seat in underdevelopment indices, there is a dire need to double the effort geared towards engineering education in the continent as past research showed that this field of study is faced with a series of challenges. Some of the challenges faced by engineering education in sub-Saharan African countries like the cumbersomeness of the available literature used by both the students and their tutors have led to a high rate of attrition, poor performance among students and a lack of diversity on the teacher's and learner's part. Also, there is a serious shortage in the number of engineering graduates produced in most countries of the region as compared to the vast challenges that require competent engineering attention in the region. Furthermore, a study conducted by ECSA showed that in South Africa, there is a wide gap across gender and racial lines in the number of students studying engineering.

Generally, technological change, continuous challenges, and engineering practice from social and professional contexts were identified as the factors that influence engineering education while comprehensive effort in engagement, appropriate contact or linkage consideration, concentration on the levers for the desired change, concentration on student-centred education, research-based development and appropriate communication, are the strategies that must be adopted by the relevant stakeholders like engineering faculty and professional societies in order to graduate engineers in the region that will be relevant in the 21st century.

Furthermore, both normal and technical collaborations were encouraged and several recommendations were given on how to reengineer the engineering education in order to capture all the elements required to graduate engineers with all the technical know-how to face the challenges of the 21st century.

It is worth noting that the findings of this review bear great significance for multiple stakeholders within the realm of engineering education in Sub-Saharan Africa. Educational institutions, policymakers, educators, students, and industry partners can all derive practical applications from the identified challenges, strategies, and recommendations. Despite the worth noting findings, the emergence of new challenges and strategies since the collection of data for this review, regional diversity owing to the vast and diverse region in sub-Saharan Africa, and depth of analysis for each of the challenges identified are some of the limitations of this review.

The insights gleaned from this review provide a foundation for positive change in engineering education in Sub-Saharan Africa. Nevertheless, we propose a series of recommendations such as continuous research and data collection, interdisciplinary collaboration, quality assurance and accreditation, frequent industry engagement, promotion of inclusivity and diversity in engineering education, and improvement of student-centred teaching methodologies will definitely help reshape engineering education in the region.

In conclusion, the future of engineering education in Sub-Saharan Africa rests on the commitment and collaboration of all stakeholders. By addressing the identified challenges and implementing innovative strategies, the region can enhance the quality, relevance, and impact of its engineering programs.

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Competing Interest Statement

The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data and Materials Accessibility

No additional data or materials were utilized for the research described in the article.

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