

Redefining Engineering Education in Africa through Delivering Total Engineering

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Abstract: Engineering education in sub-Saharan Africa has the potential to contribute to economic and social development of any country. But it has not been leveraged on appropriately to culminate in economic and social development in the countries in Africa. This implies that for Africa as a region to leverage fully on the potentials of engineering education to ensure economic and social development, it must be redefined through delivering total engineering. This study was a theoretical discourse on redefining engineering education in Africa through delivering total engineering and evidences from established literature were used in giving more credence to the work. Delivering Total engineering is a composite of three words which are delivering, total and engineering. This study conceptualized what delivering total engineering and it was defined as an educational perspective which showcases the relationship between learning and teaching which is crucial to innovation in the delivery of capable, competent and confident graduate which are the outcomes. Findings revealed that the three dimensions (delivering, total, engineering) are crucial in redefining engineering education in Africa and they were analyzed in support of this study. The study therefore recommends intensification of effort on research on delivering total engineering as it has no theoretical basis. Pragmatism is also important to verify the veracity of the concept.

Keywords: redefine, engineering, engineering education, Africa, delivering total engineering, delivering, total, engineering.

I. INTRODUCTION

Engineering was defined by the Royal Academy of Engineering as the 'creative application of scientific principles', principles that are put in practice to invent, design, build, maintain and improve structures, machines, devices, systems, materials and processes. This definition of engineering by the Royal Academy of Engineering is multifaceted and broad and it has the intent of showcasing the dynamism in engineering related industries. While engineering education is the process through which the knowledge and principles related to the discipline of engineering is being taught (Danko, 2006). Basically, engineering education is the training of engineers. With different changes taking place as man evolved, it has necessitated the impetus to redefine engineering education in Africa in order to ensure relevance. In the year 2012, the Royal Academy of Engineering (RAE) revealed that engineering education in sub-Saharan Africa has the potential to contribute to economic and social development of any country (Matthews *et al*, 2012). This implies that for Africa as a region to leverage fully on the potentials of engineering education to ensure economic and social development, it must be redefined.

Delivering Total engineering is a composite of three words which are delivering, total and engineering. To conceptualize what delivering total engineering is, each word will be defined differently. Delivering include the principles in support of engineering activities: demonstration of the requisite tools, techniques, and methodologies to enable undergraduates to become competent practitioners in preparation for an industrial career. Total implies an education that characterizes the entire through-life, lifecycle to lifestyle design, engineering and management. This implies that total implies an all-encompassing approach to delivery of education which spreads throughout the entirety of a discipline, while engineering is the learning outcomes. Thus, delivering total engineering from the works of R I. Whitefield *et al* (2019) was defined as a three-dimensional space from an engineering education perspective of principles in support of engineering activities, the scope of through life design, and the learning outcomes that will culminate in raising graduates that are competent and confident. There is much impetus to redefine engineering education in Africa such as to ensure responsiveness and relevance with the current time. It is important to note that times are changing and so are the economies, environments, conduct, context and conditions are changing too which necessitates the dire need to redefine engineering education in Africa. the Fordist era has been left since a long time ago and we are at the fourth industrial revolution which has its peculiarities for influencing the redefinition of engineering education in Africa.

II. METHODOLOGY

Methodology is pivotal in research. It is a guideline which showcases how a researcher carried out his study using the method of collecting and analyzing various data. The study adopted a logical approach to satisfy the research objectives by first reviewing the literature on the subject of delivering total engineering so as to identify how other researchers had described the concept. The subsequent step was to derive from previous authors their frameworks which were built on to lend credence to this study. With the novelty of the concept delivering total engineering, there is no theoretical basis for it and the framework developed by R.I Whitefield *et al* (2019) was built on to lend more essence to this study.

The current state of engineering education in Africa

The 20th century has amazing engineering achievements that changed the way people live and it made their lives better (Constable, G., *et al*, 2003).

Revised Manuscript Received on September 25, 2020.

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These include advances in construction, skyscrapers, roads, bridges and tunnels, heating and cooling systems, automobile devices, better communication facilities and other infrastructures that made life better for humans. According to (Center for Strategic and International Studies) at the 21st century, there are significant changes that are taking place such as the explosion of new knowledge, major demographic changes and changes in globalization, wide investment in research and development etc. This has been the basis for differentiation of countries along two divides namely the Global North and the Global South. With countries on the Global North characterized by improved economies, good infrastructures, low poverty rate and dependence on secondary and tertiary production, they have stood apart as admirable countries amongst others while countries in the Global South are also called the third world countries and they are characterized by poor infrastructure, widespread poverty, poor development, corruption, dependence on primary production, insecurity and other social vices. As a result of investment in engineering made over the years, this has been a tipping point for segregation among the countries of the world as revealed above with Africa not faring when compared to some regions.

Sub-Saharan Africa hosts 13% of the world's working age population and this number has been studied to increase to 17% by 2030 which is the second largest after Asia globally. With more than 605 of the total population under the age of 25, the region is the youngest globally and it has been revealed that by 2030, Africa will be home to more than a quarter of the worlds under-25 population. There are projections that the region will expand in size of workforce than the rest of the world in totality (GE, 2015). By tapping into this demographic opportunity, the region would be set for new economic breakthroughs made by future industries and labour market and much more than this will be increasing labour productivity and per capita income, economic diversification, talented graduates and veritable job opportunities in the decades ahead. It has been opined that engineering education as a discipline has the impetus to contribute to social and economic breakthrough in the region (Matthews *et al*, 2012) if it is effectively and efficiently leveraged on. With engineering education vital to achieving the stated ideals, it is important to consider the current status of the discipline with a view for to understand what has been and what will influence the impetus to redefine engineering education in Africa. According to the World Bank (2014), to ensure widespread economic growth and global competition, it is pivotal that Africa develops its human capital in areas such as science, engineering and technology. There exists inequality in terms of quality and investment in engineering education in countries in Africa and some countries are noticeable for their high-quality engineering resources. Compared with other countries in Sub-Saharan Africa, South Africa is reputable for having high quality engineering resources which is seen at both academic and industrial level. This typifies that the body saddled with the delivery of the knowledge of engineering which is the university and the outside industry which applies practically the knowledge gained from engineering are of admirable quality in South Africa. Evidence from research revealed that South African Council for

Automation and Control (SACAC) is the sole national member of IFAC in Sub-Saharan Africa and one of only two national member organizations in the whole of Africa as a region. This attest to the noble status of South Africa as a haven of engineering profession in Africa. though, not a perfect ideal of what should be, South Africa also has its own drawbacks and it was revealed by Mkele (2013) that 43% out of more than 700 South African engineers were of the opinion that they do not train students appropriately, and 26% were of the opinion that they might leave for other country in the future while the Engineering Council of South Africa (ECSA) revealed that an engineer services more than 3000 people in South Africa compared with 227 in Brazil and 543 in Malaysia. These all shows the inadequacy of engineering in terms of staff capability and strength.

Understanding the Impetus for redefining engineering education in Africa

There is the need for redefining engineering education in Africa as a result of many reasons. To encourage massive infrastructural development that will be in sync with the region's growth trajectory, it is vital to have such on deck and some of these infrastructures include roads, bridges, buildings, airports, harbours etc. Though all these are existing currently, there is a need to have an upgrade to these infrastructures so that it will be able to encourage the development needed in the region and also ensure competition with other regions.

Furthermore, there is a need for the region to focus on industrial development especially in manufacturing. It is important to note that Africa is blessed with all inputs needed for industrial activity and the only thing needed now is the infrastructure to adequately leverage on this vast potential the region has for industrial development. This will ensure that the region is highly diversified, depending on various economic potentials embedded in it and also the region becomes a net exporter rather than importer of manufactured goods which will aid the foreign exchange earnings in the region. Thus, there is the need to redefine engineering education in Africa.

There is a wide need for energy in Africa to overcome power shortages and help industrial activities. Africa as a region has been bedeviled with inadequate supply of power as a basic infrastructure over the years and this has affected all processes within the region. Though, some countries in the region like South Africa and Ghana have made tremendous effort at this, some still lag behind in this direction. Take for instance, Nigeria where the total output generated is less than 5000 megawatts. This has immense influence on the life of the people, industrial and economic development which necessitates the need to redefine engineering education in Africa as a region. As revealed by Matthews *et al* (2012) that engineering has the capacity to encourage social and economic development in Sub-Saharan Africa, it is important to note that the region has in it vast deposits of natural resources which are pivotal for contributing to social and economic development in the region but this has not been the case.

There are varieties of natural resources in vast deposits spread across countries in Africa and some of these include, gold, diamond, oil, copper, zinc, coal, tin, columbite, asphalt etc. This shows the potentials of Africa as a region ripe for rapid development and hence the need to harness mining and processing of these rich natural resource and exporting it. This cannot be made possible without engineering and the discipline must be redefined to ensure that the competencies, knowledge and talents required to harness these resources are contained in the curriculum of students and delivered to them appropriately. With the support of the government and vital stakeholders critical to this discourse, redefining engineering will go a long way as to ensuring that the ideals of Africa as a region with great potentials are realized while also raising its social and economic status amongst the comity of nations.

With recent changes across the globe, there are certain events that have occurred with time which needs to be analyzed. It is important to note that times are changing, hence, the need to have an overhaul in the conduct, context and environment in which engineering take place. This has necessitated the calls for responsiveness in engineering education in some quarters. It is noteworthy to understand that what obtains in time past, might be unobtainable now and there is a need to factor this in all development discourse. Take for instance the changes brought about by globalization, changing demographics, changes in the environmental conditions which culminated in climate change, economic changes and others. These changes must be factored into engineering education as a discipline to ensure that the discipline delivers on its ideals. With Africa worst hit by these changes as a result of poor capacity to adapt, it is needful to redefine engineering education so as to ensure that the discipline is relevant with time and able to contribute to social and economic development in Africa. When this is done, the growth trajectory of the region will be shaped with attendant consequences on the economies of countries in the region.

Conceptualizing delivering total engineering

Delivering total engineering is a new concept and it has no theoretical basis. Delivering total engineering concept was developed by the department of design manufacturing and engineering management (DMEM) at the University of Strathclyde in a bid to reveal the import of teaching, research and knowledge exchange activity in the university (R.I. Whitfield, A.H.B. Duffy, H. Grierson, 2019). From their research, a framework and ethos which revealed the multi-disciplinary and holistic approach to design, manufacture and engineering management.

From this framework, it is important to note that delivering total engineering is an educational perspective which showcases the relationship between learning and teaching which is crucial to innovation in the delivery of capable, competent and confident graduate which are the outcomes. In simple terms, delivering total engineering as a framework has in it the delivery of knowledge which is the pedagogic aspect which culminates in the design and development of processes and lastly the learning outcomes. Delivering total engineering is a multi-path approach framework which is

predicated on multi-actors, is interactive, iterative, directive and explorative.

The dearth of theoretical foundation for this concept is a huge challenge to build on it and any attempt to build on the frontiers of knowledge as regards delivering total engineering must take reference from its source which is the department of design manufacturing and engineering management (DMEM) at the University of Strathclyde. Understanding this will guide the advancement of knowledge along this dimension. It is vital to put in mind that knowledge is dynamic and cumulative, and as people evolve with time, they tend to gain mastery of concepts that were poorly understood in time past and build upon it. For delivering total engineering to cover the three dimensions, a spatial model was proposed and it has in it intervals for the three dimensions.

The model as proposed in the work of R.I Whitfield (2019) contains individual modules delivered in an accredited engineering programme. Some of the intervals associated with each dimension of the delivering total engineering framework are captured in table 1 below which is not exhaustive. From the intervals, it corresponds to a conventional product design and can be applicable to other processes or service design or specific product development demands within engineering as a discipline and other fields.

Delivering dimensions	Total dimensions	Engineering dimension
Abstracting	Market research	SM1b-scientific principles and methodology
Associating	Concept design	SM2b-mathematical and statistical methods
Composing	Embodiment design	SM3b-other engineering disciplines
Decomposing	Detailed design	EA1b-engineering principles
Defining	Manufacturing	EA2-performance of systems and components
Detailing	Assemble	EA3b-quantitative and computational methods
Generating	Operations	EA4b-integrated or systems approach
Standardizing	Recycle	D1-business, customer and user needs
Structuring	Disposal	D2-define the problem, identifying and constraints
Synthesizing		D3b-work with incomplete or uncertain information
Analyzing		D4-advanced problem-solving skills
Decision making		D5-plan and manage the design process
Evaluating		D6-communicate their work

Any program within the engineering education domain must be that the skills needed to become competent and qualified graduates are passed to learners. In respect to engineering education, the above intervals showcases the delivering total engineering dimension and from a glance it showcases the knowledge domain which starts from crystallizing ideas that are pivotal to addressing a problem and delivering it to learners while also evaluating it as an end process in the delivering dimension while the total looks at the whole product development process right from the initial conception which is done through market research to final disposal while the engineering dimension is the totality of the learning outcomes that must result in producing competent, talented and confident graduates. It is noteworthy to bear in mind that the smallest unit of engineering process starts with a problem which must finally culminate in a solution and it is safe to assume that engineering education ensures that transformation takes place from a problem to a solution. The delivering total engineering concept has also been reputed to be iterative in nature and it was revealed that no single outcome would lead to the termination of the process, this implies that the delivering total engineering encourages a process where multiple outcomes are delivered after solving a problem. This is also a problem-solving dimension of delivering total engineering which is quite applicable in engineering education as a discipline that seeks to create solution to various challenges as they come.

Redefining engineering education in Africa through delivering total engineering

In order to probe deeper into the crux of this study, it is important to examine what the keyword redefine is. Various authors have shed light on what the concept is and from a literal perspective, redefine means to reexamine or reevaluate with a view to change (Merriam Webster dictionary, 2020). This is apt in describing what redefining is and understanding that there is a need to re-examine or re-evaluate with the intent of changing something is important which has been captured in the impetus for redefining engineering education. Various reasons have been given for a dire need to redefine engineering education and this study seeks to conceptualize redefining engineering education in Africa through delivering total engineering. To achieve this, R.I Whitefield *et al* (2019) three's dimensions which are delivering, total and engineering captured in delivering total engineering will be looked at and analyzed. The delivering dimension refers to the principles in support of engineering activities which includes the demonstration of the requisite tools, techniques, and methodologies to enable undergraduates to become competent practitioners in preparation for an industrial career. Understand and apply learning with respect to tools, techniques and methodologies that correspond to each of these types of activities. The delivering dimension has in its nexus the curriculum, and how its delivered to become competent practitioners in preparation for their career in the society. In this context, it is apt to look at what the curriculum in Africa. engineering education curriculum as a part of the delivering dimension has not been consistent with development and changes in Africa. It is important to note that there are changes along socio-economic, environmental, and demographic lines and

as these changes occur, there is a need for new skills to emerge with new approaches to learning. The skills and competencies needed in the 21st century is different from what is obtainable in the past and there is a need for a redefinition of the elements of the delivering dimension in the delivering total engineering framework. According to Continental (2006), there are new requirements for the 21st century engineers and replete among the skills and competencies needed include technical competence, global sophistication, cultural know, innovation, entrepreneurial drive, flexibility and mobility. Much more than this, the evolutionary progress made as the society progresses delineated into industrial revolutions has in it the need for redefining curriculum which has been typified as a dimension of delivering. Though, there is still no universal consensus on what constitutes an industrial revolution (Maynard, 2015), four general phases have been identified from the perspective of the technological evolution (National Academy of Science and Engineering, 2013) and we are at the fourth industrial revolution. The fourth industrial revolution with its emerging technologies needs new tools, techniques and methodologies for graduates to fully leverage on it and become competent and confident graduate which is the outcome of the delivering total engineering framework. Hence, the need for a re-examination and re-evaluation of all the principles in support of engineering education, the tools, techniques and methodologies, learning and delivery of knowledge. To ensure this, there has been the calls for contextual relevance and Fomunyan (2020) opined in his study that new approaches to learning must be contextually relevant. We are now in the era of profound and massive changes in our fabric of existence which must be met with new knowledge relevant to this time. There are also calls for responsiveness in the curriculum to ensure relevance which has been addressed by various authors. Furthermore, the total dimension as a part of the delivering total engineering framework include education that spans the entire through-life, lifecycle to lifecycle design, engineering and management. Total includes the design and development of processes, systems, services and products and it requires a broad consideration of the whole product development process and its management. Total in engineering education must consider all life phases and the lifecycle of processes, systems, services and products and is therefore the "Total" and second dimension of the Delivering Total Engineering framework. It is important to note that engineering education has in it variety of actors and processes. Understanding all that spans the entire lifecycle of the discipline to its final disposal is king in this context. This dimension emphasizes the holistic and broad approach to processes, systems, services and products in engineering education. With engineering being the creative application of scientific and mathematical principles, it doesn't just come to play. There is a long list of processes right from initial conception of ideas to the final disposal.

Understanding each phase with a view to re-evaluating them is key in redefining engineering education in Africa through delivering total engineering. It is important to have a long list of the entire through life, lifecycle to lifecycle design, engineering and management and sequentially examining and re-evaluating each stage with the intent to redefining engineering education through delivering total engineering. More so, engineering is the context in which students are educated and which they progress with their careers, the domain or sector of application. The composite of all learning outcomes must be that the competent, confident and talented graduates are produced. The learning outcomes represent the “Engineering” and third dimension of the Delivering Total Engineering framework. Different aspects of engineering education had to be taken into account. It is therefore crucial to take a look at the contexts in which students are educated so that the learning outcome will culminate in developing competent, confident and talented graduates. Redefining engineering education will require re-examining scientific and mathematical principles and other principles and approaches that are crucial to the engineering dimension of the delivering total engineering framework. Undergraduate and postgraduate programmes delivered in engineering education must be populated with modules that ensures that the skills and competencies needed to become capable, confident and competent engineers are developed in people. The case has been made above for relevance in curriculum and context which engineering takes place while also ensuring that the whole processes from the initial stages to the final stage in engineering designed is considered in a bid to translate into veritable outcomes which are competent, confident and talented graduates. Africa as a region is in dire need of competent, confident and talented graduates to address the skill shortages in the region and to proffer solution to the many ills suffered in the region. With the advent of new technologies and changes taking place along the economy, environment and the demography, there are new problems emerging that must be met with new solutions. This is one of the ideals of delivering total engineering which seeks to showcase the relatedness of learning and teaching which is crucial to innovate clearly, providing novel approaches to issues and then translating to capable, competent and confident graduates. Delivering total engineering as an educational perspective showcases the relationship between learning and teaching which is crucial to innovation in the delivery of capable, competent and confident graduate which are the outcomes. For engineering education to be redefined, reasons have been given for the need for that while also making the case for the redefinition using delivering total engineering. In engineering education, there is the need to develop the capability for total dimensionality in the discipline and this can be made possible by redefining engineering education through delivering total engineering. With various actors crucial to engineering education as a discipline, understanding the role of each within the framework will help in shaping and redefining the discipline.

III. FINDINGS AND DISCUSSION

Findings from the study revealed that engineering education in sub-Saharan Africa has the potential to contribute to economic and social development of any country (Matthews *et al*, 2012). With the import of engineering education as a vital tool for economic and social development in Africa, it has not been leveraged on appropriately which necessitates the impetus for redefining the discipline through delivering total engineering. This implies that for Africa as a region to leverage fully on the potentials of engineering education to ensure economic and social development, it must be redefined. Findings also revealed that there is a dire need to redefine engineering education in Africa. This is necessary to ensure responsiveness and relevance with the current time. Africa is blessed with abundant natural resources which when leveraged on can culminate in social and economic development for the region. There is therefore a need for the region to focus on industrial development especially in manufacturing. With much potential for social and economic development, the only thing needed now is the infrastructure to adequately leverage on this vast potential the region has for industrial development. No region has much abundant natural resources like Africa and this has over time been referred to as a curse for the region because it has resulted to a dependence on these resources to the detriment of other viable sectors that can ensure development. The natural resources are the major resource most countries depend on in Africa and times are changing now, other nations are developing their technology and digital world which has massive impact on development. It was revealed that times are changing and so are the economies, environments, conduct, context and conditions are changing too which necessitates the dire need to redefine engineering education in Africa. global superiority amongst nations is becoming a thing now and there is this competition to outshine others which has led to other consequences. So also, is the changing economy and the environment which has various consequences on humans, systems and processes. Also, as a result of these changes, conduct, context and conditions have changed too which necessitates the need to redefine engineering education in Africa. There exists inequality in terms of their development and this can be likened to the quality of investment made in engineering education in these countries. Globally, some countries are known for their high-quality engineering resources which has culminated into better development for them. These has been the basis of differences amongst nations and some have been divided into Global South and Global North. It was also found out that delivering total engineering as a concept is still new and there is a dearth of theoretical information on the concept. It has its basis in the works of R.I Whitefield *et al* (2019) from the department of design manufacturing and engineering management (DMEM) at the University of Strathclyde.

According to R.I Whitefield et al (2019) delivering total engineering was defined as a three-dimensional space from an engineering education perspective of principles in support of engineering activities, the scope of through life design, and the learning outcomes that will culminate in raising graduates that are competent and confident. The model as proposed in the work of R.I Whitefield *et al*(2019) has individual modules delivered in an accredited engineering programme. Some of the intervals associated with each dimension of the delivering total engineering framework are captured and were used to redefine engineering education in this study.

Summary and recommendation

This study considered redefining engineering education in Africa through delivering total engineering and from the study, the current state of engineering education was considered while also examining impetus for redefining engineering education in Africa. It was revealed that there are various reasons for redefining engineering education in Africa and key amongst them include its essence as a tool for social and economic development and to ensure responsiveness and relevance with time. The framework developed by R.I Whitefield *et al* (2019) was built on to understand and conceptualize what delivering total engineering is. Delivering total engineering was defined as an educational perspective in support of engineering activities which involves the scope of through life design and the learning outcomes that will result in competent, capable and confident graduates. It was revealed that the three dimensions (delivering, total, engineering) are crucial in redefining engineering education in Africa and they were analyzed in support of this study. The study therefore recommends intensification of effort on research on delivering total engineering as it has no theoretical basis. Pragmatism is also important to verify the veracity of the concept.

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