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REVIEW ARTICLE

Change in the training mode of excellent engineers

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ABSTRACT

This paper categorized engineers into researchers and general engineers. Different institutional models for the training of engineers in some countries are highlighted and compared. Also different training modes (both passive and active) are indicated and their effectiveness discussed. The paper notes that there is a need to change the training to active learning mode typically project-based learning (PjBL) and problem-based learning (PBL) that engage students and make them to be innovative and creative. Both PjBL and PBL are based on self-direction, collaboration and multidisciplinary orientation. The paper emphasizes that changing the training mode is not sufficient to produce excellent engineers but other components of knowledge acquisition resources (human and non-human) are required to be adequate. For example, it is important to rework the curriculum to include substantial humanities that equip graduate with soft skills to complement the hard skills provided by engineering disciplines. The teachers also must have relevant competence and skills to effectively impart knowledge to the learners and the learners must have the capacity to acquire knowledge. The new normal arising from the emergence of CoronaVirus Disease 2019 (COVID-19) pandemic has necessitated the need to migrate to innovative online training mode as an alternative to face-to-face or in-place training even for courses with laboratory components without facilities for digital and remote laboratories. The reports from some countries showed that the experiences in the training of engineers during COVID-19 varied from one country to another. Proactive funding mechanism must be put in place to make available digital and remote laboratories that will replace physical laboratories so that undergraduates will have access to acquisition of knowledge in the relevant practical. The government must also provide enabling environment for learning. When all these ingredients are adequately provided, change in the training mode will produce excellent engineers.

Key words: training mode, excellent engineer, knowledge acquisition resources, coronavirus disease 2019, digital and remote laboratories

INTRODUCTION

Engineers are trained to design, evaluate, develop, test, modify, install, inspect and maintain a wide variety of products and systems. They also recommend and specify materials and processes, supervise manufacturing and construction projects, conduct failure analysis and provide consulting services as well as educate the next generation of Engineers. Engineers are to use scientific ideas to develop technology (endogenous technology) that are relevant to the development in their areas of operations. Engineering deals with solving societal problems in sustainable ways. The problems to be solved are defined by the society, which also defines the acceptability of any prescribed solution(s). The proffered solution(s) must satisfy conflicting requirements of cost, safety and efficiency. The application of engineering to solve problems in sustainable ways is essentially cultural and often localized. What is good engineering solution in one context may be bad in another. For example, the deployment of a combined harvester to a rural community that has no means of maintaining or sustaining it, is a bad engineering solution to an agricultural problem while the introduction of a motor vehicle transport where there are no roads would be

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an impossible solution to a rural transportation problem.

Engineers are categorized into (1) Researchers and (2) General Engineers. It was suggested by Mariasingam that teaching and research should be separated and be given equal importance. He opined that the two should be the responsibility of two departments.[1] Each Department has the primary responsibility of either teaching or researching. Going by what operates in some countries, engineers (research and general) can be trained in a number of ways: (1) Japanese model, in which university provides broad education in engineering and industry, provides the engineers with technological specific training. (2) Establish two types of universities as in USA- research universities and universities with emphasis on teaching. These patterns of universities also exist in Singapore where 4-year conventional (theoretical) programs are offered at the National University of Singapore while another 4-year practice oriented Bedrock of Industrialization' Proceedings of a 3-day International Workshop on programs are offered at Nanyang Technological University. (3) Establish two different faculties within each university. One faculty produces theoretical (research) engineers and the other faculty offers practice-oriented Bedrock of Industrialization' Proceedings of a 3-day International Workshop on programs. Many universities in USA have those two faculties: one offering Bachelor of Science in Engineering Bedrock of Industrialization' Proceedings of a 3-day International Workshop on programs and the other Bachelor of Engineering Technology Bedrock of Industrialization' Proceedings of a 3-day International Workshop on programs. (4) Britain offers specialist Bedrock of Industrialization' Proceedings of a 3-day International Workshop on programs and general degree Bedrock of Industrialization' Proceedings of a 3-day International Workshop on programs under the heading An Integrated Engineering Degree Programme. (5) Adopt a unified system and allow the industry to have sufficient input both in term of teaching and provision of on-job training to complement university efforts rather than waiting to get fully baked engineers.

The first option is attractive; it allows the universities to concentrate on producing graduates with broad knowledge in engineering while the industry provides on-job training experience for the students. But will the industry be willing and capable of providing such training? The second alternative is good. This option will definitely minimize the cost of research equipment procurement in all universities, as only those that are research-oriented would need many items of equipment. But will the industry leaders be willing to go to classrooms to teach or will the students be willing to pursue such specialist Bedrock of Industrialization' Proceedings of a 3-day International Workshop on programs? Are the industry leaders available in the right quality and quantity? Options (3), (4) and (5) show that all the universities must be equipped equally. The fifth option is what exists in Nigeria and from all indications, the option is expensive and the lean financial resource is grossly inadequate to equip all the faculties of engineering and technology in Nigerian universities and therefore, this constitutes a major reason for inadequate facilities in the faculties of engineering. The option of having few universities that run research Bedrock of Industrialization' Proceedings of a 3-day International Workshop on programs in engineering and others offering technological Bedrock of Industrialization' Proceedings of a 3-day International Workshop on programs will go a long way to alleviating the problem of inadequate facilities for teaching and research in faculties of engineering in the universities.

TRAINING OF ENGINEERS: A CASE STUDY OF NIGERIA

Training is teaching or developing in oneself or others any skills and knowledge that relate to specific useful competence. The training of engineers is through formal education and it takes place in higher educational levels, polytechnics/colleges of technology and/or universities, after the prospective candidates have earned good grades in relevant science courses in the secondary schools. The routes for acquiring a degree in any engineering discipline, taking Nigeria as a case study (Figure 1).

Figure 1 shows that a prospective engineer commences his/her training from primary school which is usually a 6-year programme. At primary school level, a would-be engineer will show flare for mathematics. The quality of instruction is ensured by employing trained teachers to teach the pupils. After the completion of primary school, a pupil gains admission to secondary school or technical college after passing the qualifying examinations. In the secondary school, the pupil is introduced to relevant science subjects (Physics, Chemistry and Mathematics/Further Mathematics). In addition to the science subjects, a student in technical college is introduced to hands-on and the use of relevant tools. He may later pursue further study in the polytechnic or College of Technology. The requirements for admission of students into engineering programs in Nigerian universities are specified in the Minimum Academic Standards. Generally, the requirements are that prospective candidates should have passes at credit level in the senior secondary school (SSS) final year examinations or general certificate of education ordinary level examinations (GCE 'O' Level) in five subjects including Physics, Chemistry, Mathematics, English language and one other subject. For Direct Entry, candidates must have passes in Mathematics, Physics and Chemistry at general certificate of education advanced level (GCE 'A' level) or equivalent. Holders of national diploma (ND) and Higher national diploma (HND) with minimum of upper credit level are eligible for consideration for admission into 200 and 300 levels of university programs

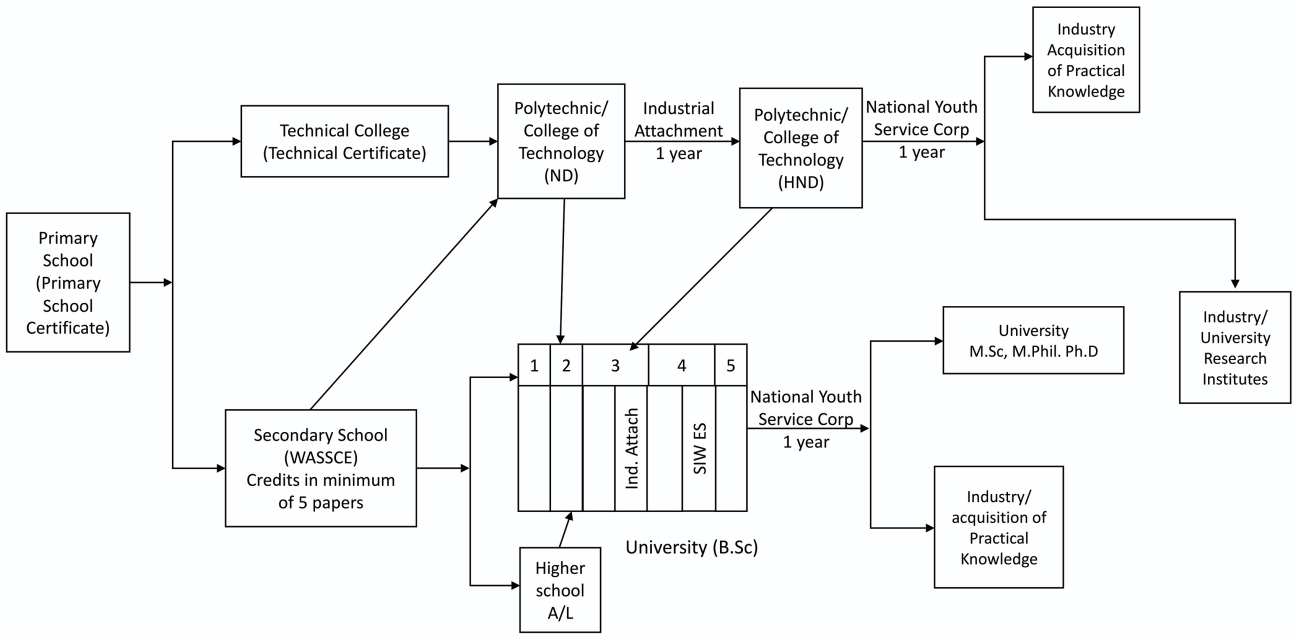

Figure 1. Knowledge acquisition processes for prospective engineers. Source: Falade.[2] WASSCE: West African Senior School Certificate Examination; B.Sc: Bachelor of Science; M.Sc: Master of Science

respectively. Candidates for admission into 100 level engineering programs in tertiary institutions are required to have acceptable passes in unified tertiary matriculations examinations (UTME) and post-UTME examinations. However, a university can decide on certain criteria that will enhance the quality of its candidates, for example, apart from the general requirements, University of Lagos insists that prospective engineering students in addition to the above requirements must earn credit in Further Mathematics in senior secondary certificate examinations (SSCE) and that all the credit passes must be at a sitting. The impact of the additional requirement of credit in Further Mathematics has been evident in the quality of engineering graduates produced from University of Lagos.

Generally, each country set the objectives of engineering training for her prospective engineers. For examples, the objectives of the engineering training in Nigeria are in consonance with the realization of national needs and aspirations vis-à-vis industrial development and technological emancipation. The graduates are expected to be resourceful, creative, knowledgeable and able to perform the following functions: (1) Design engineering projects and supervise their implementation. (2) Design and implement components, machine, equipments and systems. (3) Design and develop new products and production techniques in industries. (4) Install and maintain complex engineering systems so that they can perform optimally in our environment. (5) Adapt and adopt exogenous technology in order to solve local engineering problems. (6) Be able to exercise original thought, have good professional judgement and be able to take responsibility for the direction of important tasks. (7) Be able to manage people, funds, materials and equipment. (8) Improve on indigenous technology to enhance local problems solving capability.[3]

The philosophy and objectives of engineering Bedrock of Industrialization' Proceedings of a 3-day International Workshop on programs in the universities indicate high expectation from engineering graduates in terms of high academic standard and adequate practical background for self-employment as well as being of immediate value to the industry and the community in general. These objectives can only be achieved if proper mode of training is adopted and other ingredients of knowledge dissemination and acquisition are put in place including competent teachers to train the engineers.

TRAINING METHODS

Training methods refer to the principles used for instruction. These methods include class participation, demonstration, recitation, memorization, or combinations of these methods. These definitions imply that training should assist students acquire knowledge or develop appropriate skills to make them function well in the industry after graduation or to be self-sustaining and be employers of labor and not job seekers. Training method can be broadly classified into passive and active types. The passive method is also called traditional method while the active methods engage learners and train them to be creative and innovative, the passive method does not. The traditional training method consists in teachers reading out lecture notes while students sit submissively and take notes. This is not an effective way of developing knowledge or understanding among learners. Active training methods are chiefly: (1) Team-based learning (TBL), (2) Problem-based learning (PBL), (3) Project-based learning (PjBL), (4) Experiential learning, (5) Outcome-based learning, (6) Co-operative learning (CL), (7) Flipped classroom, (8) Technological enhanced learning.

TBL

TBL is a training method that uses groups of students in the learning and teaching process in a collaborative manner. It is the use of learning groups to enhance students' engagement and the quality of students.[4] TBL was developed by Michaelsen *et al*.[5] as a potential solution to the problems of large classes. This method allows the involvement of an individual to contribute to the works of others. The contribution of the members of the team is assessed through peer evaluation and the overall team contribution are factored or weighted into the overall grading of each student.

PBL

In PBL, students are placed in the active role of problem-solvers confronted with situations like the kind of problems they are likely to encounter in future. This method of training develops in learners, thinking strategies, domain knowledge, and flexible knowledge, effective problem solving skills, self-directed learning, effective collaboration skills and intrinsic motivation.[6] In PBL, the teacher acts as the facilitator and mentor rather than a source of "solutions" to the problem. The method assists the students to try out what they know, identify what they need to learn, develop skills for achieving performance, improve their communication skills and equip the students with information to defend their positions. It provides opportunity for the students to apply theory to practical problem and equip them with problem solving skills that will make them to be industry-ready after graduation.

PjBL

PjBL is similar to PBL. Both methods are based on self-direction, collaboration, and multidisciplinary orientation. PjBL has been proved to be one of the effective student-centred strategies in engineering education in many fields.[7] PjBL is based on inductive approach where students' task is to collaboratively formulate and find answer to question related to course consent. Depending on the type of course, PjBL requires longer period of time than PBL; it is more directed to the application of knowledge while PBL is directed to the acquisition of knowledge. This method is also used with TBL because of large students' population in classes. The impacts of PjBL was highlighted by Balve and Albert,[8] Beier *et al*.[9] Guo *et al*.[10] They are namely (1) Collaboration and negotiation skills, (2) Teamwork, (3) Good communication and presentation skills, (4) Project management skills, (5) Constructive feedback, (6) Skilled in acquiring information for problem-solving, (7) Interdisciplinary thinking.

Experiential learning

It is the process of learning by doing. By engaging students in hands-on experiences and reflecting on the experience acquired by doing. Experiential learning focuses on creating experience that have practical application of knowledge and skills to real-world experiences to increase learner's knowledge and develop competence in skills and behaviours. The first step of the experiential learning model is "Experience". The experiential learning educators purposefully engage with students in direct experience and focused reflection in order to increase knowledge, develop skills and clarify values.

Outcome-based learning

The concept of outcome-based education considers a precise clarification of intended learning outcomes; these outcomes represent students' desired performance of particular abilities or competencies.[11] The pivotal characteristic of the outcome-based pedagogical approach is the emphasis placed on the learning outcomes that are intended to be achieved in the learning environment. The method shifts the emphasis to the question of what abilities the students should possess on the completion of the course.

The outcome-based pedagogical approach of Biggs and Tang[12] also features the constructive alignment principle, which prescribes the alignment of the individual instructional elements with the intended learning outcomes. Biggs and Tang[13] indicate that outcome-based design model comprises three parts: the intended learning outcomes, the teaching and learning activities and the assessment tasks.

CLs

CL is a teaching approach whereby students work in teams on assignment or project under conditions, which include the team members being held individually responsible for the complete content of the assignment, or project. Usually, after a test has been given and graded, the performance of the students is used to sort them into groups that ensure weak students are put in the group of bright students. Some students, especially, the bright ones, do not admire this method because they see it as weighing them down. The use of this method requires mentoring and counseling of the students.

Flipped classroom

In this method, many students' preferences can be addressed using technology. Teachers can make lectures available to students whenever and wherever it is convenient to them, at home, in class *etc*. Teachers can deliver their lectures and/or instructions by recording and screen casts of work they do on their computers, creating videos of themselves teaching. Instead of talking about phenomena, videos and computer simulation can be used to provide detailed visual representation. Students can access these videos as often as they want. Rather than delivering lectures in the classroom, teacher then use the classroom period to actively engage students in learning process and attend to each student's need since adequate time is available for discussion.[14] Using video can be better than real life because it enables the instructor to play it over and show it in slow motion if necessary.

Technological enhanced learning

In technological enhanced learning also called E-Learning, electronic media and information and communication technology are deployed in education to enhance the transfer of knowledge and skills. E-Learning includes multimedia learning, computer- based training (CBT), internet-based training (IBT), web-based training (WBT), online education, virtual learning environment (VLE) *etc*. Well-designed multimedia application offer potential for reduction of time for formal instruction. E-learning can occur in or out of the classroom. With technological advancement, students can use computer or mobile device to access learning materials anywhere in the world.

IMPACT OF CORONAVIRUS DISEASE 2019 (COVID-19) ON TRAINING OF ENGINEERS

The emergence of COVID-19 pandemic created restriction to movement and interaction among the citizenry. This negatively affected the face-to-face interactions between engineering educators and the learners and thus necessitated the need to migrate to innovative online training mode in engineering. Migration to innovative online teaching in engineering education will amount to teaching engineering courses without hands-on laboratory experience by students where there are no remote laboratories. This will make it difficult for engineering students to appreciate real life situation as depicted through experimentation in the laboratory. Lack of practicals will adversely affect students' understanding of some theoretical concepts that are usually demonstrated in the laboratories. The absence of laboratory/workshop practicals as integral part of the engineering education training will contribute to the diminution of the quality of engineering graduates. The laboratory and workshop experiences provide students with opportunities to interact with equipment and tools leading to accumulation of knowledge and skills in engineering education. Usually, in the laboratories students are exposed to the use of equipment and possibility of carrying out experiments of theoretical concepts and collect data for analysis and model the experimental results to establish whether a theory adequately describes a physical event and validate or establish a relationship between the measured quantities (data) and the underlying physical principles. Some design data are also obtained through experimentation in the laboratories. Access to equipment and relevant tools afford students to innovate and be creative. Fabrication and carpentry works are also part of the trades to which the students are exposed in the workshops. Students also work in teams that give them opportunity to develop skills in working with others. It is difficult to anticipate how all the above attributes can be achieved in an innovative online engineering education mode. There is no good virtual substitute for field trips or academics exchanges. Digital or remote laboratories are needed as alternatives to in-place laboratories for effective online training mode.

I serve as a member of a global Engineering Education Working Group (EEWG). At the meeting of the working Group in April, 2023, issues bothering on the effects of COVID-19 on the training of engineers were raised and discussed. Members of the group were requested to report briefly on each member's country experience in the training of engineers during the pandemic. Some extracts for some countries are presented below. The names of the presenters are in brackets:

Nigeria (Funso Falade)

Initially the pandemic caused a full shutdown of the universities. When they began to reopen, it was in a socially distanced, health-conscious manner. These precautions led to issues with space and technology, as large lecture classes could not be conducted. There were also problems with housing. Delayed graduations meant that new students could not come to the university as the housing was still occupied by the delayed graduates. Tutors felt overloaded, and students suffered from the lack of campus social life. For online content, the national network infrastructure was inadequate, frustrating both instructors and students. For the future, the importance of this infrastructure, and for devices for the students, and hence, more funding is a strategic imperative.

South Africa (Elsabe Kearsley)

As with other countries, South Africa pivoted to online over a 2-week period and stayed online for 2 years. The third year (2022) was hybrid, and now all are back to in person. The sense is that online is fine for lectures and meetings, many other aspects of education (labs, internships, social interactions, teamwork skills) require face to face and hands-on experiences. "Education is more than instruction" was a useful insight. In order to maintain the full instructional load, teachers and staff had reductions in their vacations. The pandemic highlighted new aspects of inequities-rural populations do not have the same network infrastructure and devices and may have different pressures in economic downturns. There were also concerns about ethics in an online world, particularly around assessment.

Argentina (Raul Bertero)

The University of Buenos Aires has 13 schools, 30,000 teachers and 400,000 students. During the pandemic, instruction was entirely virtual. Now most curricula are entirely in person, the exception being computer science which retains a large virtual component. After the pandemic, 400 teachers across 8 provinces were asked their views on the digital experience. There were favorable opinions of the enrichment provided by digital methods, the readiness to address a future similar crisis and the likelihood that hybrid instruction will continue. There were mixed opinions on whether online courses are effective, particularly in fields that require hands-on professional practice.

United States (Joanna Livengood)

Dr. Livengood cited a number of government and professional society studies on the effect of the pandemic on education in the United States. At the preuniversity level, the gap in achievement, particularly in mathematics, widened between white and non-white students; all students dropped in math achievement during the on-line years. Universities are seeing incoming students with uneven or reduced skill levels and are adding resources to assist them. Enrollment in universities (of all types) has declined, as did graduation rates in 2020. A survey of 6000 higher education students found that more than 50% of students felt they would have trouble completing their degrees and that they would struggle to find a job, an internship, or the expected earnings for their field. The biggest issue from the pandemic is student mental health, but the issues of integrity and equity will need to be addressed. Students with disabilities faced more hardship. During the pandemic, 1 in 5 university students reported food insecurity.

United Kingdom (Shaun Holmes)

Dr. Holmes raised a new topic, of the financial sustainability of institutions during and after the pandemic, as student fees and particularly international student fees, dropped. As engineering is more expensive to teach than other disciplines, privatized institutions may lean away from engineering for the sake of their business solvency. He also commented on the huge workforce disruptions of the pandemic, which affects the potential for employment for graduates. Some businesses have retained more digital/online work than pre-pandemic, which may affect the skills graduates need to be successful, and thus affect curricula and instructional methods. The pandemic highlighted socio-economic equity issues; even in urban settings not all families have the devices necessary for multiple family members to engage in online content. He has concerns about the pipeline of students currently in secondary school; the number of female students enrolled in higher level math courses has dropped, perhaps because during the lockdown years they were exposed to societal and family views of their potential, with no counter-narrative coming from the school setting. The Research Assessment Exercise (RAE) is embarking on a systems-thinking approach to the question of how and why students enter engineering and how to improve that pipeline.

China (Zhongping Li)

During the pandemic, all instruction was virtual. It is now a hybrid, with most teaching in person, but new technology (for example virtual laboratories) in use. He felt that the new instructional methods are more efficient. New capabilities were developed during the pandemic, including a lot of on-line contents that are available on a global scale. He emphasized the importance of addressing an inclusive, flexible, and inventive mindset going forward.

Germany (Karen Wagner)

Initially both teaching and exams were on-line. Each university has its own methods and chooses its own platform, so it is difficult to assess at a systems level. Digital content has been retained, but there is only a slight increase in blended learning now that in person instruction has resumed. She believes that instructors were not well trained in how to create, and make use of, digital methods. On the other hand, the students do not want to return to entirely in person instruction. To address this, not only is there a need for greater instruction and technology for the teachers, but there need to be appropriate (private, quiet) spaces and technology for students to access digital content. There were no issues with digital assessment, in fact in some cases the results were better because students had no other distractions than to study. Enrollment by female students has dropped, and there is a concern about having sufficient skilled workers for the future. She also noted a loss of student resilience, and the need for more support for students than in the past.

The above summarized the experiences in the training of engineers during the COVID-19 in selected developing and developed countries around the globe.[15]

EXCELLENT ENGINEERS

Engineering training provides discipline specific skills (hard skills) that are learned through the training period. These skills enable the possessors to solve emerging problems consistent with the acquired skills. However, our economy requires much more than acquisition of engineering skills. Soft skills (critical thinking, creativity, teamwork, *etc.*) are rooted in arts. Soft skills relate more to emotional intelligence and natural abilities that enable people to navigate their environment, work well with others, perform well and achieve better results. The need to incorporate soft skills into engineering necessitated the need to integrate Arts into Engineering. The method of incorporating soft skills into engineering curricula varies from one country to another depending on the regulatory bodies.

Generally, "change", according to Goldberg and Somerville,[16] requires three stages namely, (1) unfreezing, which involves both creating the motivation to change and belief that change is possible, (2) learning, which involves taking on new concepts, new standards and new interpretation of old concepts and standards, and (3) internalizing, or refreezing, these new concepts and standards. All the three stages recognize that there are multiple ingredients to change, both rational and emotional and that change takes time and attention to process.

The production of excellent engineers will require change in training mode but the change may not be sufficient without addressing other change requirements namely, reworking of the curriculum. There is a need for an effective partnership between industry and academia. When academia collaborates with industry, the engineering curriculum can be aligned with real-world needs, ensuring that students are technically competent and well versed in the challenges and opportunities that await them in the professional share Zhou *et al*.[17] The new curriculum should include substantial project work, both technical and interdisciplinary with sufficient provision for humanities in the course contents. Sustainability must be embedded within the core engineering subjects and offering specialized courses that provide a deep dive into the principles and practices of sustainable development. A comprehensive competency examination for the engineering educators is necessary and they must understand and imbibe the three stages of change. The educators must also have relevant skills to use the most educative training modes typically, PjBL and PBL that equip students with problem-solving skills, self-direction, collaboration and multidisciplinary orientation. The goal is to produce engineering practitioners who are not technically adept but also socially responsible and environmentally conscientious.

Excellent engineers must acquire good training that equip them with requisite skills to practice in any part of the world such engineers must qualify as global engineers. A global engineer must have global competence. Parkinson defined a new set of skills,[18] which he collectively refers to as "global competence" and has compiled a list of 13 dimensions of global competence: (1) Appreciation of other cultures. (2) Ability to communicate across cultures. (3) Familiarity with the history, government and economic systems of several countries. (4) Ability to speak a second language at a conversational level. (5) Ability to speak a second language at a professional (i.e. technical) level. (6) Proficiency in working in/or directing a team of ethnic and cultural diversity. (7) Ability to effectively deal with ethical issues arising from cultural or national differences. (8) Understanding of cultural differences relating to product design, manufacture and use. (9) Understanding of the connectedness of the world and the workings of the global economy. (10) Understanding of the implications of cultural differences on how engineering tasks may be approached. (11) Some exposure to international aspects of topics such as supply chain management, intellectual property, liability and risk, and business practices. (12) Experience of practicing engineering in a global context, whether through an international internship, a service learning opportunity, a virtual global engineering project or some other form of experience. (13) Ability to view themselves as "citizens of the world" as well as citizens of a particular country; appreciate challenges facing mankind such as sustainability, environmental protection, poverty, security and public health.

The above competence is only possible when the developed curriculum integrates engineering with arts contents and the training mode equip the graduates with skills to operate globally at high competent level. There is a need for innovative collaboration among all stakeholders to prepare 21st century engineering practitioners who are capable of driving sustainable development. Government can provide an enabling environment through grants, research funding, tax incentives, and policy formulations that prioritize and reward sustainable practices.[19]

CONCLUSIONS

From the foregoing, the following conclusions are made: (1) There is a need to change the training mode of engineers to PjBL and PBL that engage the students and provide a platform for them to collaborate among themselves. (2) There are multiple ingredients to change, both rational and emotional and change takes time and attention to process. (3) The curriculum must be reworked with adequate provision for humanities, social sciences, business management concepts and entrepreneurial skills development. (4) The educators must also have relevant skills and competence to implement the active training mode. (5) When other ingredients are in place, change in training mode will equip graduates with excellent knowledge for them to operate as excellent engineers.

DECLARATION

Author Contributions

Funso F developed the concept for the manuscript, reviewed the literature, formulated research questions, collected the data, conducted analyses and interpreted the data. The author read and approved the final manuscript.

Conflict of Interest

Funso F is an Editorial Board Member of the journal. The article was subject to the journal's standard procedures.

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