Open Biomedical Engineering Education in Africa

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***Abstract*— Despite the virtual revolution, the mainstream academic community in most countries remains largely ignorant of the potential of web-based teaching resources and of the expansion of open source software, hardware and rapid prototyping. In the context of Biomedical Engineering (BME), where human safety and wellbeing is paramount, a high level of supervision and quality control is required before open source concepts can be embraced by universities and integrated into the curriculum. In the meantime, students, more than their teachers, have become attuned to continuous streams of digital information, and teaching methods need to adapt rapidly by giving them the skills to filter meaningful information and by supporting collaboration and co-construction of knowledge using open, cloud and crowd based technology. In this paper we present our experience in bringing these concepts to university education in Africa, as a way of enabling rapid development and self-sufficiency in health care. We describe the three summer schools held in sub-Saharan Africa where both students and teachers embraced the philosophy of open BME education with enthusiasm, and discuss the advantages and disadvantages of opening education in this way in the developing and developed world.**

I. INTRODUCTION

The scarcity of accessible quality healthcare is one of the biggest problems in Africa and other developing countries [1]. This is not only due to the unavailability of resources but also to the absence of a structured framework for high level training in the design and management of healthcare facilities. In addition, in much of the African continent, medical equipment does not have common standards or operating protocols. Indeed in most developed countries, hospitals and clinics have very expensive maintenance contracts with manufacturers who train their own specialized technicians. As a result, the medical device industry in Africa (we refer in this paper to sub-Saharan Africa excluding South Africa) is largely absent and there is an over reliance on foreign companies to repair and design biomedical instrumentation, and resolve technical problems.

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The experience of one of the authors in the EU funded Asialink project, "Development of Core Competencies in the areas of Biomedical and Clinical Engineering in the Philippines and Indonesia" (2005-2008) has shown us that long term and sustainable improvements can only come through i) recognition on the part of policy makers, of the importance of in loco trained experts capable of managing and repairing biomedical equipment and ii) development of expert skills through individualized programmes that cater to the specific social, cultural and technological needs of a region [2]. These are the two keys to a sustainable and efficient health care system.

However, the world has completely changed with respect to 2008, when the ASIALINK project was considered a landmark in education. The continuous connectivity with tablets, mobile phone, the rapid dissemination of social networks, and the access to free e-learning makes teaching easier and harder at the same time, because of the huge amount of available information.

The world of BME is also changing, here again thanks to various communities that live and discuss on the web. While, a couple of years ago, the development of biomedical devices was essentially linked to companies and universities, now the first examples of open source biomedical devices, such as the Gammasoft Open electrocardiogram and the Smartpulse oximeter are beginning to appear [3] [4]. Although these instruments are not accurate or safe enough to be inserted in the clinical routine, their use can probably save a life more than a damaged, unused (e.g., for high operating costs) or useless (e.g., because no one knows how to operate) X-ray computed tomography.

Despite this virtual revolution, the mainstream academic community in most countries, developed or not, remains largely ignorant of the potential of open source software, hardware and prototyping or the availability of web-based self-teaching resources. This is particularly evident in Africa where tradition and hierarchy play a strong role at all levels, more so in academia [5]. The authors are of the opinion that academia, and specifically biomedical engineers in higher education, must embrace these new tools, and pass on the message that an Open Source product, developed by a community, easy to modify and develop, without a multinational brand name is not equal to unreliable.

We present here a paper on the benefits and use of Open Source tools and platforms in Biomedical Engineering education particularly in Africa, which needs to jump on the fastest, cheapest and greenest wagon to growth and

self-sufficiency in healthcare. The experience of transferring technology and know-how to a consortium of African Universities is described, and the advantages and disadvantages of adopting "Open Source BME education" (OS4BME) is discussed in the African and global context.

II. CONTEXTUALISATION

A. Crowdsourcing and Crowdthinking Platforms

Currently there are several resource sharing platforms available on the internet. Their use is spreading throughout the World, starting from Europe and the US [7][8][9]. The growing accessibility of these platforms, like any shared common resource, has resulted in the generation of huge amounts of garbage. Sifting the useless from the useful is a monumental task and requires experience in design and engineering as well as some skills in negotiating the now cluttered internet of things. More importantly, at present there are no specific engines or platforms focused on the sharing of biomedical instrumentation and devices [10][11]. This is because, by their very nature, biomedical devices possess stringent performance requirements to comply with regulatory standards to ensure patient safety. Thus, in the BME context, we still need a level of supervision, to control the quality and to guarantee the respect of safety standards. By virtue of their access to the brains of the future, universities are the right (and perhaps the only) institutions to properly teach instruments for crowd-"doing", while giving due importance to concepts such as ethics, standards and regulations. However, few universities make use of the newer technology platforms for teaching this discipline and even more worrying is that fact that very few universities do BME core competencies including knowledge on standard and regulatory pathway development for medical devices.

B. Contextualizing Biomedical Engineering for Africa

Very few African universities offer BME courses. Those that do are based on curricula which were designed for Western universities over 20 years ago, which place undue emphasis on niche subjects like MEMs and cell engineering and less on the learning of new, hard technology and equipment management, maintenance and repair [6]. On the other hand, a needs-based curriculum which gives students the capacity to solve problems and find new solutions using the world they have access to through their phones and tablets would be far more useful for growth and development.

Fusing the crowd design philosophy with the BME's objective of improving human healthcare requires that patient safety and efficacy be the paramount concern and also the motivating force behind Crowd driven innovative biomedical device design. Biomedical devices must be designed with safety and efficacy in mind, and they should adhere to regulatory standards (albeit most of the countries in the region of interest have no regulatory authority for biomedical devices). Thus the Crowd not only needs to be empowered with the technological know-how, but also be given the means to intelligently scan and filter the internet for useful open source materials without being overwhelmed by choice available. To do so requires fundamental knowledge on biomedical devices, ergonomics, engineering and human physiology coupled with a solid grounding in biomedical device regulations and standards.

Leaving aside large diagnostic and imaging equipment and prosthetic implants, the vast majority of biomedical devices have a large turnover and no one company monopolizes the market. In this arena there is huge scope for Crowd driven improvements and innovation. Three key steps are required to give Biomedical Engineers in sub-Saharan Africa the tools and know-how in order to design, develop, maintain and market their own equipment based on the new open hardware and open source revolution:

- the development of human resources in higher education in Biomedical Engineering in Africa;
- the creation of an a sharing, making and repository platform (based on the customization and integration of already available web tools) for vetting, searching and ranking designs to propel continuous improvement and innovation;
- the creation of a new genre of Biomedical Engineer in Africa with i) the capacity to exploit and develop innovative designs on the platform and of discriminate use of web based and open source resources, ii) versed in the regulatory aspects of biomedical safety and standards, and iii) equipped with entrepreneurship skills to build innovation into industries, a strategy that also addresses socio-economic growth.

C. Tools for OS4BME

We have identified five main areas of teaching, necessary for opening BME education:

- rapid prototyping through additive manufacturing technologies;
- electronic prototyping systems;
- content management and sharing platforms;
- regulatory and safety compliance in design;
- Business development for medical technology.

These elements need to be integrated into a BME curriculum and adapted to the local social, economic and cultural needs.

III. THE INNOVATORS' SUMMER SCHOOLS

The Innovators' Summer School (ISS) is an initiative of UNECA (United Nations Economic Commission for Africa) and is a strategy aimed at fostering the economic development of Africa by stimulating biomedical innovation and improving higher education. TA total of three ISS have been implemented to-date.

The first exploratory summer school was held in Kampala (Kyambogo University) in 2012. During this event the participating universities formed the Africa Biomedical Engineering Consortium (ABEC) with the mission of bringing excellence to BME education in Africa. ABEC's logo, the result of a student design competition, is reported in Figure 1.

The second and third Innovators' Summer Schools were held in Nairobi at Kenyatta University in August 2013 and

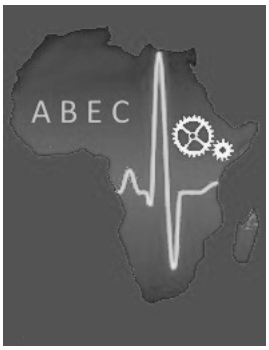

Fig. 1. The ABEC logo

in Daresalaam in December 2014, respectively. Here the focus was on a series of intensive courses to demonstrate the potential of regulated open source design, prototyping and innovation to students, academics and regulators/decision makers. The aim of the intensive one-week courses was to introduce the OS4BME education concept to the African Engineering community and thus create a small working group who will be involved in the set-up of a virtual resource platform. To fulfill this objective, the first course was focused on the design of a biomedical device from first principles, assembling and testing of the device and discussion of the regulatory issues involved. The second went a step further and was based on design improvements and aspects of marketing and business development. Over 35 students, technicians and lecturers per year from Kenyatta University (Kenya), University of Nairobi (Kenya), University of Eldoret (Kenya), Addis Ababa University (Ethiopia), Makerere University (Uganda), Kyambogo University (Uganda), Mbarara University (Uganda), University of Malawi (Malawi), Muhimbili University of Health and Allied Sciences (Tanzania), University of Zambia (Zambia) and University of Pisa (Italy) attended the courses.

A. 2^{nd} Summer School: Introduction to Biomedical Device Regulations and Rapid Prototyping

After introductory lessons to explain the aim of the course, and some basics on rapid prototyping hardware, software, electronics, and safety regulations, hands-on sessions were provided, giving to the students the opportunity to learn by doing. During the course we underlined the importance of needs-based design and development, focusing on the respiratory problems of new born premature babies and the monitoring of breathing and body temperature. Here the goal was to design and build a low cost device, for monitoring respiratory movements and temperature, able to shake the cot to resuscitate the normal breathing of the baby when it stops, and equipped with a sound and light alarm to call a nurse to the cot. The implementation of these features was established together with students, after an intense brainstorming session. Importance was given to the functional aspects of the devices as well as their cost, feasibility safety and reliability. Students were divided into groups devoted to the study of i) needs based design, ii) safety and ISO compliance, iii) electronics, and iv) prototyping (Figure 2).

At the end of the course an evaluation survey was conducted by the funders. The results indicated that only one participant had previously been exposed to open source technology. All participants expressed extreme satisfaction in the course, although more than half of them could have benefited from previous knowledge on electronics, CAD and programming.

There was also interest in the regulatory aspects and standards in medical devices. As the participants were from different backgrounds, many had very little idea what medical devices are and the critical importance of safety issues in such devices. The action thus served to bring home the importance of this aspect during the design of instruments for BME. To encourage safe design and innovation, the summer school ended with a student project competition organised by ABEC. With the help of lecturers and mentors, students were encouraged to spend the next year working on their own ideas for presentation at the following summer school.

Fig. 2. The Innovators' Summer School 2013, at Kenyatta University

B. 3^{rd} Summer School: From Making to Marketing

The summer school in Daresalaam was hosted by the Muhimbili University of Health and Allied Sciences and was jointly run by the University of Pisa and SIDO (Tanzanian Small Industries Development Organization), who regularly hold courses on business development. The objective of the school was to design a simple device (a small ultraviolet sterilizer) and take it through the product development, business planning and marketing stages. The course began with a presentation and preliminary assessment of all student projects. Then the UV sterilizer was examined from a technical and design point of view, comparing its performance and safety with other sterilizer devices. Locally available materials and resources were selected for fabricating the device and students were allocated small components to design, prototype and assemble. In parallel experts on intellectual property protection, business planning, and marketing from SIDO showed the students how to take a product through all the phases of medical technology innovation and business development (identify, invent, and implement). With the concepts in place, students were given

the opportunity to work in groups and present their business and marketing strategies for the product or products they had been working on for the competition. On the last day of the summer school the students re-presented their projects in a 10 minute pitch; the difference between the pitch and the first day's presentation was remarkable, and clearly demonstrated the impact of the 4 days of training and mentoring. Once again the response from students, professors and technicians involved in the school was enthusiastic.

IV. Discussion and Conclusions

In this paper we describe the aims and philosophy of OS4BME, a new concept in BME education based on the use of open resources and cloud and crowd based teaching and learning, and its first applications in an African context.

While we are not advocating a revolution in BME teaching here, we are strongly in favour of the upgrading of curricula based on solid engineering principles (similar to those outlined by Linsenmeier [12]) with new courses, new technology, new ways of thinking and problem solving and high technology business development, specifically adapted to the needs of countries with few resources-or like many western economies, in dire need of a spurt of growth.

The ISS, organized to kick-start the OS4BME initiative, provided the following indications:

- this teaching strategy is generally acceptable and well suitable to the African context where BME training is in its infant stages and with infrastructural and human resource challenges;
- the rotation of the ISS between countries of member Universities with the involvement of existing local expertises and stakeholders in the training of students enhances ownership of the program and encourage student continuity in pursuing their innovations;
- the dissemination process of skills gained at the ISS to individual universities is still lacking. This can potentially be addressed by having a strong parallel focus on training of trainers in addition to students.

In parallel, the ABEC was demonstrated to be good platform for allowing inter-university collaboration and sharing of resources to ensure high-quality BME education.

We thus argue that the new virtual sharing mentality should be wholeheartedly embraced, valorised and overseen by African (and indeed all) universities through the development of a dynamic needs-based curriculum and a common platform rendering the design, development, and maintenance of medical equipment accessible to trained Biomedical Engineers. However, the adoption of these new methods of creating and thinking needs to be coupled with open standards and regulations for medical device safety. A note of caution: the freedom given by the Web, and by the possibility to share, fork and re-implement projects, which characterises the Open Source Software, Electronic, and Hardware world, has one major drawback: organizing information (schematics, blueprints) is the boring part that in a passion-driven (and self-assembled) community is not always pursued. In the context of BME however, this latter aspect is critical for ensuring safety and efficacy of biomedical devices, and must go hand in hand with the adoption of open resources for medical applications. The BME academic community must ensure that students are equipped with sufficient fundamental safety and design knowledge and the capacity of discrimination to make judicious use of open and cloud based resources.

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