Nurturing next-generation biomedical engineers in Africa: The impact of Innovators' Summer Schools

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Abstract

The mission of healthcare systems in Africa to deliver compassionate and effective care has been constrained by growing populations, increasing burden of disease, political conflict and limited resources. The impacts of these constraints can be substantially alleviated, and the healthcare services strengthened, through the creation and adoption of affordable, accessible and appropriate biomedical engineering systems and technologies. There is an urgent need for building capacities in biomedical engineering, innovation and entrepreneurship in African countries. The African Biomedical Engineering Consortium has been organising a series of Innovators' Summer Schools to meet this need by empowering students and researchers with entrepreneurial and innovative skills, and facilitating the design and development of robust, appropriate, and commercially viable medical systems and devices. In this paper, we analyse and discuss the impact of six of these schools held between 2012 and 2017. We used a questionnaire-based survey to collect responses from students who had attended the summer schools. The results of this study demonstrate that the teaching-learning model adopted in the ABEC summer schools was largely effective in promoting biomedical engineering skills, career choices, professional networks and partnerships amongst young African engineers and life scientists who attended the summer schools.

Keywords: biomedical engineering, health technology, education, design, innovation

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Introduction

Many existing healthcare delivery systems in Africa are in distress due to financial, organisational, and human factors. These systems are crippled by decaying infrastructure, high burdens of disease, growing populations, lack of funding, and shortage of materials (including essential consumables, drugs, and equipment). In addition, these systems suffer from inadequate training, 'brain drain' of their workforce and unaffordable healthcare services for poverty-stricken citizens (Akukwe, 2006; Albutt et al., 2018; Di Pietro et al., 2020; Fonjungo et al., 2012; Tumukunde, Sendagire & Ttendo, 2019; WHO, 2010a). These factors impede the delivery of high-quality compassionate care. Given the global push towards cost-effective universal healthcare, there is a need for sustainable, creative and innovative strategies to provide preventive, curative and rehabilitative services that meet the Sustainable Development Goal No. 3 of promoting good health and well-being in African countries (United Nations, 2015)March 2017</style>. Technological innovation can play a key role in meeting this goal and effectively provide the needed healthcare services.

African healthcare services have a major deficiency in suitable medical devices and equipment. The World Health Organization (WHO) estimates that 95% of medical equipment in low- and middle-income countries (LMICs) is imported and 80% of equipment funding comes from international donors. In sub-Saharan Africa, 70% of medical equipment is estimated to be donated with only 10-30% of donated equipment being operational (WHO, 2010b). Defects and failure of medical equipment can lead to delays in diagnosis and treatment, over- or under-treatment, long-term health risks, high out-of-pocket healthcare costs, long hospital stays and, worst of all, loss of life (Akukwe, 2006; Albutt et al., 2018; Di Pietro et al., 2020; Fonjungo et al., 2012; Tumukunde, Sendagire & Ttendo, 2019; WHO, 2010a). Similarly, equipment maintenance and repair operations usually experience long delays as most of the support infrastructure and skilled maintenance staff come from developed countries (Ahluwalia et al., 2015; De Maria et al., 2020).

Numerous strategies have been suggested to address poor technology transfer to the developing world. These include creating national-level policies for donation regulation and management, adopting open-source technologies and subsidizing the cost of medical equipment destined for the developing world (De Maria et al., 2020; De Maria et al., 2018; Lustick & Zaman, 2011). However, medical technologies obtained from developed countries cannot offer lasting solutions for LMIC problems as the harsh environmental and climatic conditions, unreliable main power supplies and poor infrastructure in LMICs are typically overlooked in the design process (Di Pietro et al., 2020). It is therefore necessary for engineers in LMICs to innovate sustainable solutions and overcome the issues of medical device adoption (Lustick & Zaman, 2011; UNECA, 2018). Biomedical engineering can improve healthcare systems by designing sustainable solutions (coupled with training and maintenance schemes) that are appropriate for the developing world. Moreover, it is of paramount importance to establish biomedical engineering education programs on the African continent. These programs would enable the training of the next generation of leaders and thinkers who can navigate the social, political and structural complexities of their countries, and design and develop the most appropriate medical technologies for these countries (Ahluwalia et al., 2015; Douglas, 2012; Douglas et al., 2017; Lustick & Zaman, 2011).

Impelled by the dual goals of guiding innovation and improving health technology in Africa, the United Nations Economic Commission for Africa (UNECA) led the initiative in May 2011 for exploiting "engineering expertise to improve health outcomes in Africa." This initiative focused on building biomedical engineering skills, innovation and entrepreneurial capacities in African countries. To achieve these goals, the initiative aimed to promote and support the development of biomedical engineering undergraduate programmes at interested universities, stimulate innovation through international design competitions and advance technological and entrepreneurial capabilities (UNECA, 2018). In 2012, the initiative supported the establishment of the African Biomedical Engineering Consortium (ABEC, www.abec-africa.org), a regional platform for promoting innovation and entrepreneurship in healthcare infrastructure and technologies. The consortium is composed of 17 universities from eight countries across Africa, one research institute in Africa and six partner universities and institutions in the United States and Europe. The ABEC regional platform enables the African universities to support and promote biomedical engineering training in their institutions of higher learning and to inspire healthcare innovations among students and researchers through the establishment of competitions and awards, including primarily the annual ABEC Innovators' Summer Schools (ISS).

Annually, the ABEC steering committee identifies a new ISS theme based on healthcare challenges and clinical needs in Africa, which can be addressed using technology. Once the theme has been decided upon, the call for applications is publicised across partner institutions and collaborators. The application process is divided into two stages: the first is the submission of a 1-page concept note, while the second is a more detailed execution plan for an innovative medical device or system. At each submission stage, the applications are reviewed by a multi-disciplinary selection committee from a variety of institutions. The review criteria include the potential impact on healthcare, novelty and innovation, system design, and multi-disciplinary team composition. For each team selected in the second round, one representative is invited to attend the ISS on a travel grant. The ISS involves an intensive one-week project-based learning experience with lessons, workshops, keynote talks and hands-on group projects. The keynote talks are either inspirational, academic or practical talks focused on the ISS theme. The talks are run by selected expert industrialists, biomedical engineers and entrepreneurs from Africa and beyond. This exposure allows the students to gain a wide range of practical skills and knowledge of the innovation process, starting from ideation to marketing or entrepreneurship. For the hands-on projects, groups are formed with a balance of gender, cultural background and skills. Each group is assigned 2-3 mentors and works collaboratively on one of the successfully submitted projects. The groups promote multi-disciplinary and multi-cultural solutions while enhancing diversity and internationalism (Ahluwalia et al., 2018). The ISS aims to offer supplemental knowledge and skills in the innovation process beyond what individual university curricula can perhaps provide. At the end of the ISS, a final presentation of the work of each group is done and assessed, and three groups are awarded certificates of recognition for innovation, social impact and economic impact, respectively. All participating students also receive certificates of participation. Because the ISS hosting is rotated between African countries and multi-national students and mentors are attracted, the ISS also serves as a platform for fostering strong networks among the students, exposing them to international mentors and strengthening their collaborative skills.

In this study, we sought to measure the success of the six ISS (see Table 1) organised by ABEC between 2012 and 2017, in impacting the students' innovations and increasing their design, innovation and entrepreneurial activities beyond the Schools.

Table 1: Key information on the six Innovators' Summer Schools reviewed for this study.

Location	Dates	Theme	Participants
Kyambogo University, Makerere University, & Uganda Industrial Research Institute (UIRI), Uganda.	6th – 10th August 2012	Harmonisation of biomedical engineering curricula in Africa. Launch of ISS and creation of ABEC.	20
Kenyatta University, Kenya.	12th – 16th August 2013	Introduction to biomedical device regulations and rapid prototyping.	30
Muhimbili University of Health and Applied Science, Tanzania.	8th – 12th December 2014	From making to marketing.	33
Addis Ababa University, Ethiopia.	11th – 15th January 2016	Application of mobile phones in healthcare product design and development.	43
Cairo University, Egypt.	23rd – 27th January 2017	Biomedical and clinical data and informatics for development in Africa.	39
Kenyatta University, Kenya.	11th – 15th December 2017	Reducing child mortality.	39

Methods

Study design and population

The ISS experience of the participants was evaluated using an online survey, created on Google Forms, and run between January 2018 and August 2018. The online survey was prepared in consultation with the ABEC founding members. After agreeing upon the final survey structure, the functionality of the survey link was assessed and pretested by the study team. The survey link was sent to all archived email addresses of student participants of the six ABEC ISS that had taken place from 2012 to 2017. Participation in the survey was voluntary and each prospective respondent was prompted to accept a consent statement before taking the survey. Each student was invited and reminded to participate in the survey through two monthly emails.

Structure of Questionnaire

The questionnaire was divided into three major sections. The first section aimed to collect the demographic information of each applicant as well as the employment status at the time of the survey, the summer school(s) attended and the overall ISS experience using a linear scale of 0-10 (where 0 = poor and 10 = excellent). The second section investigated the impact of the ISS on the participants' innovative design skills, networking and teamwork skills, business and entrepreneurial skills and the influence the ISS has had on their career choices, particularly related to biomedical engineering. Likert scale-type questions were used, with response options ranging from 1 to 5 where: 1 = strongly agree, 2 = agree, 3 = neutral, 4 = disagree and 5 = strongly disagree. To assess the ISS impact on the participants, the questions considered several factors: whether new knowledge of innovation had been acquired, if new innovation skills had been acquired, if the participant's interest in innovation had been enhanced and if the entire ISS process had led to improvements in the projects carried out during the ISS. The survey also investigated how the ISS boosted the interest and skills of the participants in entrepreneurship, business planning and networking. The third section of the questionnaire, comprising open-ended and yes/no questions, sought to assess the strategic influence of the ISS through investigating the long-term ISS outputs such as completed or new prototypes, start-up companies, grant applications and awards or continuation of studies.

The survey responses were saved in a Microsoft Excel file for data cleaning prior to analysis.

Data Analysis

Analysis was performed using R version 3.6.0 and Jamovi version 1.1.9. Respondents' demographics and overall ratings of the ISS experience were described using proportions and median with interquartile range, respectively. All indicators of ISS impact and respondents' recommended improvements were described using frequency and proportions and presented as bar-graphs where appropriate.

Results

Descriptive statistics

A total of 48 students responded to the online survey. Majority of the respondents (79%) were male which reflects the gender disparity at the summer schools despite the large systematic efforts by the ISS organisers to achieve equal female representation. This disparity is due to the persistent challenge of female under-representation in the science, technology, mathematics and engineering fields. Most of the respondents who self-identified as being employed (68.8%) reported being affiliated with either private, public or government institutions while all the unemployed respondents indicated they were still university or college students at the time of the survey. Table 2 indicates the number of students who attended each of the six ISS of interest to this study. The ABEC ISS were only open to students from member higher education institutions. At the time of their initial ISS attendance, respondents were students distributed across 15 African universities: three in Uganda (n =17), three in Kenya (n = 11), two in Tanzania (n = 8), three in Ethiopia (n = 5), two in Malawi (n = 4), and two in Egypt (n = 3). Most of the respondents (91.6%) were pursuing or had obtained bachelor's degrees at the time of their first ISS attendance while the remaining respondents had diplomas. The main fields of study were biomedical or biosystems engineering (60.4%), medicine (12.5%), computer engineering (10.4%), electronic or electrical engineering (8.3%), mechanical engineering (6.3%) and planning or management fields (2.1%). While many respondents (56.3%) had attended innovation competitions in their countries of residence, the ISS was the first international innovation competition for many (79.2%). The respondents were positive about the ISS with all indicating they would recommend the ISS to other students and gave the ISS experience a median score of 9 [IQR: 8-10].

Table 2: Descriptive statistics of 48 students who participated in the ABEC Innovators' Summer Schools between 2012 and 2017.

Characteristic	**Frequency (%)**
Sex	
Male	35 (72.9)
Female	13 (27.1)
Country of residence at time of interview	
Uganda	17 (35.4)
Kenya	11 (22.9)
Tanzania	8 (16.7)
Ethiopia	5 (10.4)
Malawi	4 (8.3)
Egypt	3 (6.3)
Working	
Yes	33 (68.8)
No	15 (31.3)
Physical disability	**1 (2.1)**
Number of ISS attended	
1	37 (77.1)
2	8 (16.7)
3	3 (6.7)
Location of Innovators' Summer School	
Uganda, 2012	9 (15)
Kenya, 2013	8 (13.3)
Tanzania, 2014	10 (16.7)
Ethiopia, 2016	14 (23.3)
Egypt, 2017	10 (16.7)
Kenya, 2017	9 (15)

Impact of the ISS on students

The study investigated the impact of the ISS on the respondents' innovation, business, entrepreneurial and networking skills as well as on their career choices.

Innovation

The assessment results presented in figure 1 show that the respondents positively received the ISS content on innovation with over 70% strongly agreeing or agreeing that the ISS exposed them to new knowledge of innovation, empowered them with new design skills and enhanced their interest in innovation. A slightly lower percentage of respondents (68.6%) reported that the ISS led to improvements in the ideas or projects on which they were working.

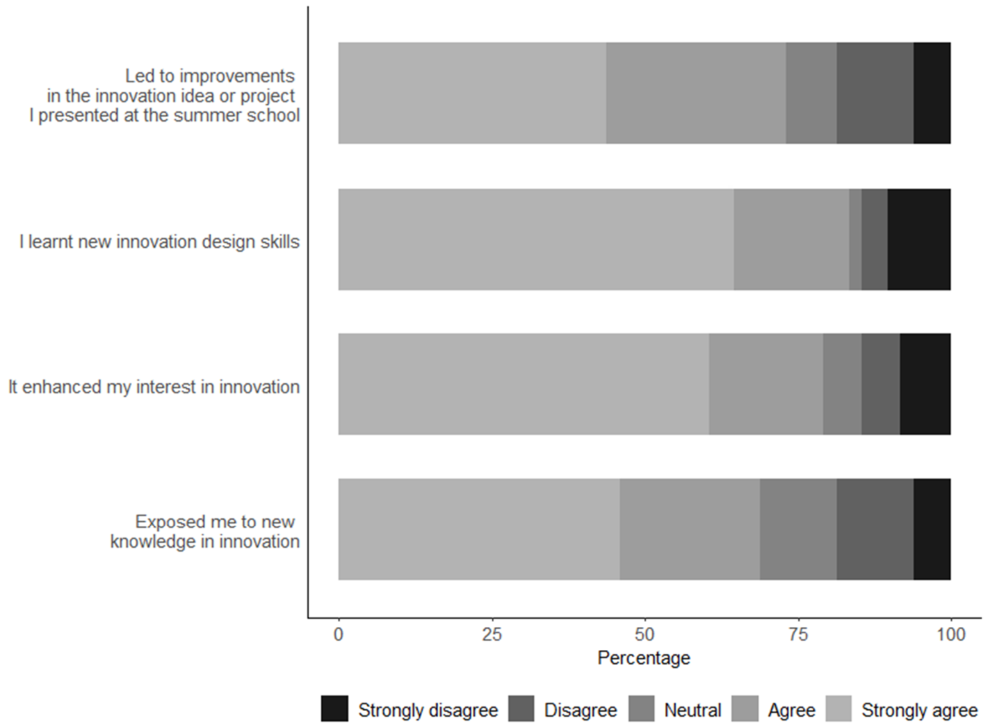

Figure 1: Summary of the respondents' opinions on the ISS impact on their innovation knowledge and skills.

Networking

Of all the respondents, 75% strongly agreed or agreed that the ISS increased their professional and student network and enabled them to make new strategic friends. This finding corroborates the positive impact the ISS had on the student participants (see figure 2).

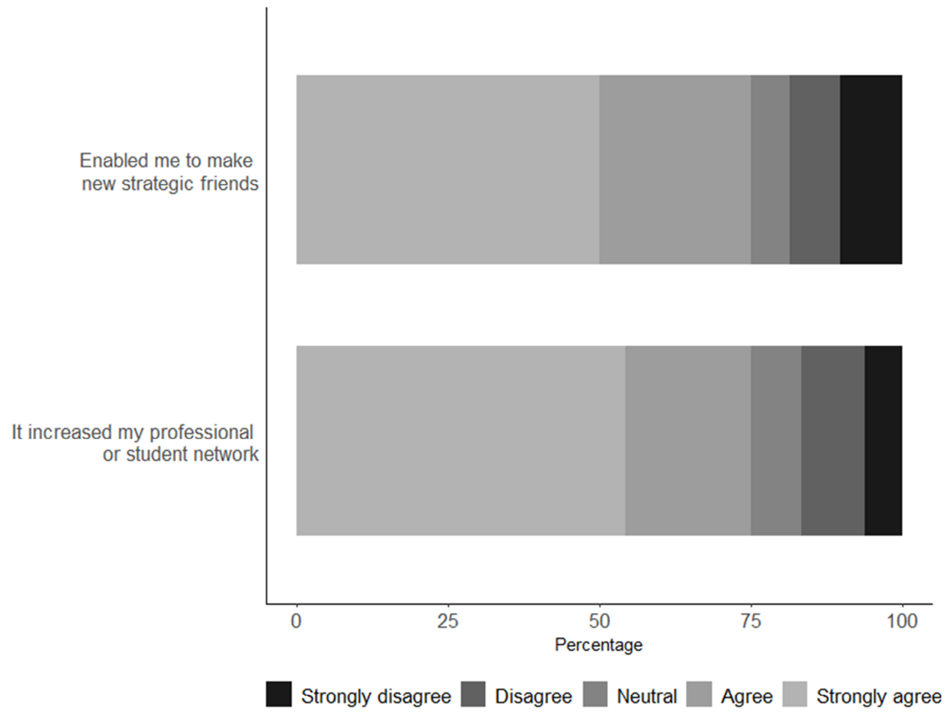

Figure 2. Summary of the respondents' opinions on the ISS impact on their student and professional networks.

Career

Figure 3 summarises the respondents' opinions on the effect the ISS had on their career paths. The summer schools had a major influence in fostering interest in biomedical engineering for 75% of the respondents. When asked if the content of the summer school supplemented skills acquired in their home institutions, 66.7% of the respondents either strongly agreed or agreed. For the 33.4% of respondents who were either neutral or disagreed, the ISS was advantageous in exposing them to new skills. For 64.6% of the respondents, the ISS influenced their academic career choices as well as their professional careers and workplace choices. Half of the respondents felt that the skills acquired supported them in securing jobs after school completion, bearing in mind that 15 respondents indicated they were still students.

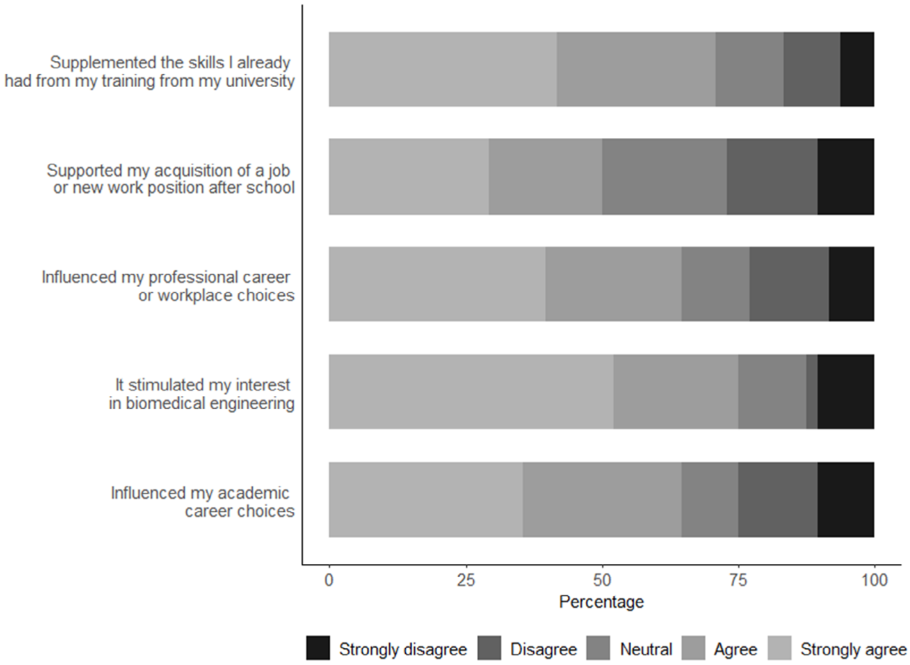

Figure 3: Impact of the ISS on the respondents' career choices.

Business

The ISS had a strong positive effect on enhancing the respondents' entrepreneurial interests with 75% agreeing or strongly agreeing with this claim. In addition, 69% of respondents strongly agreed or agreed that their entrepreneurial and business planning skills were enhanced (see figure 4).

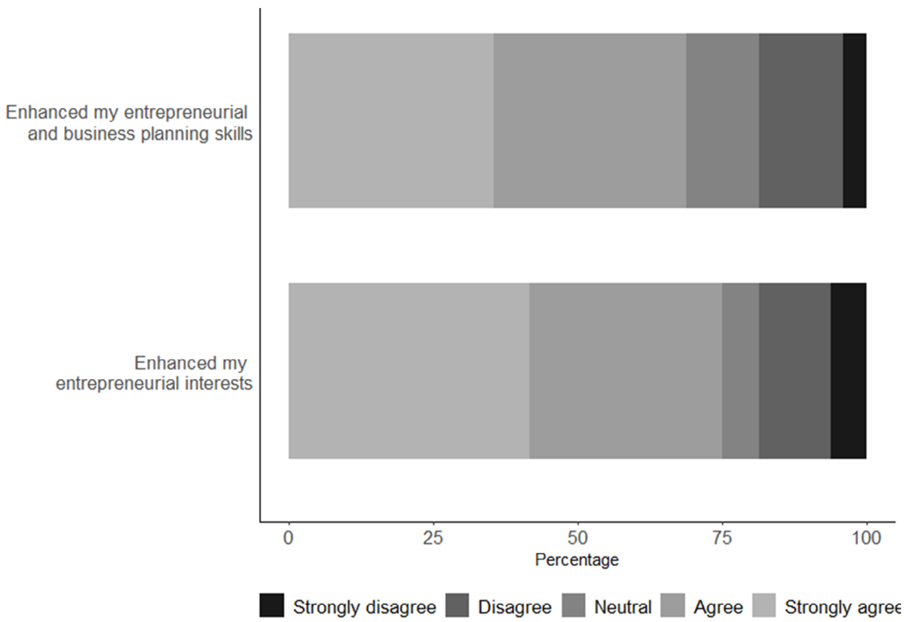

Figure 4: Impact of the ISS on the respondents' entrepreneurial and business skills.

The results suggest that the ISS series met its goal of creating and nurturing innovation and entrepreneurship competencies.

Post-school innovation experiences

The survey examined whether the participants had continued their projects, started new projects, applied for grants or joined the workforce upon ISS completion after returning to their home institutions of higher education.

Following the ISS, 54.2% of the respondents won additional innovation awards from other organisations. Twenty-one respondents (43.8%) were able to continue on their projects beyond the ISS to various self-reported milestones; including website developments, mobile application creation, prototype fabrication, user-based testing, grant and patent applications, conducting clinical trials or surveys and writing journal publications. Those who were unable to continue with their work reported various limiting factors such as lack of funding, lack of materials, busy schedules due to schoolwork or other projects, loss of interest or morale, or project non-viability. Many (91.7%) maintained contact with the connections they had made at the ISS and used these connections to: share jobs, find internship or funding opportunities, mentor one another, collaborate on projects, share technical knowledge or follow up on each other's progress. With the information they had gained from the ISS, 87.5% of respondents went on to train and mentor other innovators.

Furthermore, 94% of the respondents got involved in developing new innovations with 64.6% of them reporting that they had developed new prototypes. Half of the respondents joined innovation hubs/centres to gain expertise and access materials, while 27% of respondents reported they had submitted or secured a patent. However, it is not clear if the patents are from new projects or the ISS ones. Realizing that funding is essential for project progress, half of the respondents indicated they had applied for grants with 33% success rate among those applicants.

Following the completion of their respective programmes, 13 respondents indicated they had pursued further education, at either masters or PhD level, with 9 joining graduate programs in biomedical engineering or related fields. Other self-reported gains from the ISS include improved writing and presentation skills, enhanced teamwork abilities, acquired leadership skills and exposure to machine learning concepts. In one instance, a respondent stated that they were able to start a company that currently employs 10 individuals from their community. All the respondents showed interest in the creation of an alumni group and assisting with future ISS as organisers, facilitators, mentors or keynote speakers.

The respondents suggested interlinked areas in which they needed support and on which the ISS should focus and improve. These areas include: following up on, supporting and funding, successful projects to commercialisation; discussing the environmental impact of the innovations; elevator pitch training; offering more travel scholarships to increase student representation at future summer schools; incorporating programming classes; teaching more practical biomedical engineering skills; offering teleconferencing for those who are unable to attend; offering a pre-package prior to the ISS to familiarise participants with the required content; publicizing ISS more effectively; and facilitating interactions with potential end-users through hospital visits. Additional topics the respondents wished to see in future ISS, included human-centred design, conducting systematic reviews, intellectual property issues, legal support, mobile application development and three-dimensional design.

Discussion

Overall, the ISS series achieved its goal in creating an interest in innovation and entrepreneurship as well as allowing the participants to create lasting professional and student networks. In many cases, the participants were able to continue with the innovations they were working on during the summer schools, producing outputs such as publications in peer-reviewed journals. The ISS also fostered an interest in biomedical engineering, motivating participants to either work in or pursue further education in related fields.

One major concern was the time constraints and the intensive structure of the summer schools. Future ISS could explore models that allow extended periods of collaboration through on-line activities. One such model is that described by McCullough et al. (2019) where students from Arusha Technical College in Arusha, Tanzania and Clemson University in South Carolina in the United States collaborated on a design project through formal video-conferencing group meetings, e-mail, and various social media platforms. The year-long collaboration culminated in a joint design symposium in Arusha where the students presented their work. An innovative platform such as UBORA could also facilitate co-design and collaboration and may also be used to foster networking between ISS alumni (Ahluwalia et al., 2017). UBORA is an online platform for open source co-design of new solutions to global healthcare challenges. Furthermore, an online meeting format through that platform could be used by participants who are unable to attend the ISS physically. Such models would also allow a more in-depth study of innovation from the ideation and research phase all the way to commercialisation. Internet connectivity may however be a limitation.

Continuous follow-up on participants' projects and personal growth is an area of improvement that could be addressed with the creation of an ISS alumni group. The alumni group would keep track of the progress of every project and be a channel for sharing information about design schools, job and funding opportunities as well as collaborations.

Reflecting upon the ISS outcomes and the participants' comments, there is a clear need to support promising innovations towards commercialisation. Incubation hubs based at individual institutions, or collectively at national or regional levels, would provide such support, but would require an initial investment by institutions, industry, governments or funding agencies to render them self-financing and self-sustainable.

Conclusion

The goal of the ABEC ISS is to create and nurture entrepreneurial and innovative skills among students and researchers leading to the design and development of robust and commercially viable medical devices that address Africa's healthcare problems. In addition, the ISS events aim to provide a learning space that promotes the development of technical and the creation of professional and social networks. Participants' overall ISS experience was positive with many students reporting that they acquired and utilised new skills either for personal projects or in the workplace. While there is room for improvement, the ISS pedagogical model has largely provided students with skills that they have transferred to real-world contexts.

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Author contributions

All authors participated equally in conceptualisation of the study. D Atwine was responsible for study design and data collection. D Atwine, JM and AA developed the methodology and were responsible for project management. D Atwine and YWK were responsible for data curation and analysis and for the writing of the manuscript. All authors contributed to manuscript review and editing.

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