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A systems thinking approach to collaborations for capacity building and sustainability in engineering education

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Abstract

The general decline in the retention of professionally qualified engineers in academia and industry vary from country to country and has been attributed to different reasons for industrialized and industrializing states. This paper focuses on the outcome from a Royal Academy of Engineering (RAEng) initiative in Sub-Saharan Africa, aimed at enriching engineering education through fostering strong links between industry and academia. A systems thinking model was developed to address the weaknesses and enhance the successes of the RAEng intervention in order to build capacity for sustainability in engineering education. The model was developed and based at the University of Zimbabwe as the hub, collaborating with 6 other regional universities. This paper advocates for scaling up the largely successful initiative while capitalizing on experiences and collaborations with institutions from the United Kingdom (UK) and envisaged partnerships with other institutions from Europe.

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Keywords: Capacity building; industry-academia partnerships; engineering education; sustainability; systems thinking

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1. Introduction

The availability of engineers throughout the world differs from country to country but the general trend has been the insufficiency in their numbers [1]. The scarcity of engineers in industrializing countries was largely due to a lack of motivation brought on by insufficient training, lack of equipment and exposure to modern techniques [2], while for industrialized countries such as the UK, it has been a general lack of interest due to a perception of lower rewards in engineering [3]. Research output was seriously affected by the lack of appropriate equipment, which prompted the establishment of the Network of Users of Scientific Equipment in Eastern and Southern Africa (NUSESA) in 1989, supported by the Swedish International Development Cooperation Agency (Sida), with a mandate to develop long term strategies for sustainable development through the improvement of procurement, use and maintenance of scientific equipment [4]. The NUSESA project revealed that engineering equipment in the institutions were in poor working conditions, obsolete or underutilized due to maintenance challenges, aging or lack of expertise respectively [5]. However, the network was short-lived as the financial support from Sida soon ran out. The migration of professional engineers from Southern Africa partly contributed to the low capacity utilization experienced by most Zimbabwean companies, a mirror reflection of the other SADC countries albeit at different scales.

In response to the challenges in retaining engineering skills within the profession, the University of Zimbabwe (UZ) and the University of Dar es Salaam (UDSM) were selected to drive the RAEng initiative on Enriching Engineering Education Program (EEEP) in Southern and Eastern Africa respectively [6]. The EEEP facilitated the association of Sub-Saharan Africa engineering faculties through sharing and disseminating knowledge and best practice in order to stimulate a synergistic raising of standards in engineering education across the region [6]. The UZ partnered with Spoke Institutions (SIs) and other organizations as shown in Fig. 1. The program ran from 2013 to 2015 through 3 main activities, i.e. the secondment of engineering staff to industry to equip them with requisite industrial experience, knowledge sharing workshops as well as professional training. While the EEEP initiative was largely successful, it could only be sustained within the 2-year period due to funding constraints. This paper provides details on what was accomplished as well as building on the achievements to resolve weaknesses by developing a holistic systems thinking model for capacity building and sustainability in engineering education.

Fig. 1. EEEP Hub and Spoke Arrangement.

2. Background and literature review

The shortage of appropriately skilled engineers impeded economic growth and retarded efforts to fight poverty, diseases and other global challenges that affected the world [7]. This also adversely affected capacity for sustainable development due to failure to cope with the effects of rapidly changing technology [7]. Southern Africa suffered from a persistent lack of engineering capacity according to studies in Malawi [8], Mozambique [9], Rwanda [10], South Africa [11], Tanzania [12] and Zimbabwe [13]. Since 2011, the RAEng-led Africa-UK Engineering for Development Partnership engaged extensively with engineering communities in Southern Africa through thematic workshops aimed at identifying and prioritizing the most pressing issues facing the profession [2]. Deficiencies in engineering education were noted as factors that impacted negatively on the profession's ability to contribute optimally to economic and social development [2]. This observation was noted by other researchers in that there was a clear consensus that a key part of any strategy to build engineering capacity in Southern Africa was the improvement of tertiary engineering education [6, 14]. Although global standards of living have improved significantly over recent decades, many ordinary people in Sub-Saharan Africa did not have the same access to water, power and healthcare enjoyed by those in the industrialized world [6]. In 2015, Malawi and Mozambique were affected by heavy floods [15] and in 2017, Southern Africa was affected by a strong tropical cyclone Dineo [16], both resulting in extensive damage to infrastructure. A lack of sufficient infrastructure meant people struggled to leave areas of devastation, putting them more at risk of waterborne diseases. Industrialized countries have 20-50 engineers per 10,000 population, whilst some African countries have as little as one for the same population count [1]. Policy makers in Southern Africa have not invested enough in engineering education mainly because of lack of resources and thus relied heavily on foreign aid, which was not only unsustainable but, in some cases, insufficient [6]. Significant and sustained investment in engineering was a clear way of improving the quality of future engineers, hence the need to foster collaborations between academia and industry in order to improve access to new technology [14].

Studies have revealed the prevalence of passive and demotivating traditional teaching methods and outdated teaching materials in Africa [17]. Other related studies maintained that engineering education in Southern Africa can be improved through collaborations between Higher Education Institutions (HEI) and industry to ensure the relevance of curricula to industrial practice and developmental needs [18]. The absence of links between HEIs and industry, created qualified but unemployable professionals partly due to the mismatch of skills required by industry and those with fresh graduates from universities [18]. Due to rapid changes in industrial development, technical education systems also needed to be reviewed to keep pace with the changes and equip students with relevant skills [18]. As part of continuous efforts to produce knowledgeable, practical and socially responsible graduates, HEIs in countries such as the UK and Malaysia have incorporated industrial attachment for engineering lecturers for short-term secondments to improve lecturers' practical skills and perspectives [18]. The RAEng also facilitated intense visiting professor programs in the UK where practicing engineers were engaged by universities to offer specialized courses to engineering students, thereby bridging the gap between industry and academia [6]. However, the depressed economic environments in Southern Africa made these arrangements difficult to achieve, due to insufficient mentors and the possibility of overstretching the few available ones [17]. A holistic systems thinking approach may be an effective way to resolve such challenges through a process of reductionism in which elements of the system can be broken down and synthesized by relating their individual functions [19], which has been successfully applied in assessing risk in public private partnerships where projects were executed in 'joined up' rather than 'deterministic' ways [20].

Some countries have benefited from bridging the gap between industry and academia by embracing initiatives such as the Newton fund in Thailand [21], India [22] and South Africa [23] for the Industry-Academia Partnership Programs (IAPPs). However, the major challenge for such programs in Southern Africa was the inability to offer the same level of support and logistics [6]. NUSESA and EEEP achieved some degree of success but fell short in sustainability and continuity. The economic challenges faced by Southern Africa required a different approach, hence the thrust of this research for developing a systems thinking model buoyed by the brief but successful interventions by NUSESA and EEEP, in order to maintain a level of continuity in the otherwise noble initiatives. The model proposed in this paper combined the required skills in engineering and mapped them with the technologies used by engineers together with organizational policies as a base to sustain and retain these skills for capacity building in engineering education.

3. Enriching engineering education in Southern Africa

This research utilized a systemic philosophy and systems methodology [24] by exploring aspects of engineering education and training holistically by factoring in other distant but linked aspects such as policies towards the development of human capital. This was the basis on which the research was modelled around the EEEP initiative with a special case study focus on HEIs offering engineering education as well as some selected engineering companies in Zimbabwe. Engineering institutions in Sub-Saharan Africa were faced with the widening gap between young and inexperienced academics and the few old and mostly retired professional engineers [6]. Apart from the inability to confidently dispatch their teaching duties, young engineers were also unable to carry out research let alone publishing, resulting in inadequately trained engineers, a challenge for regional accreditation [6]. The implementation plan developed by the UZ for the EEEP was modelled around the use of mid-semester vacations where some academic and technical staff were seconded to local companies for at least 6 weeks. The companies ranged from telecommunications, power systems, manufacturing, mining and mineral processing, construction, transportation, water engineering and surveying. During the secondments, lecturers were exposed to various work areas in order to be equipped with the skills and attributes shown in Table 1.

Table 1. Expected outcomes from academics' and technicians' industrial attachment

Activity	Outcomes/Attributes	Skills/Competences
Industrial secondment	Access to modern equipment/techniques	Relevant experience
Exposure to modern equipment	Ability and confidence to teach	Appropriate technology
	Practical Research/R&D Solutions	
Networking with engineers	Ability for consultancy, CPDs and income generation	Industrial management
	Strengthening industry-academia links	
Industry based projects	Artefacts and prototypes	Practical problem solving
	Practical teaching and student projects	
Joint research with industry	Research publications in journals & conferences	Academic scholarship
	Research for development	

Apart from the universities and local organizations shown in Fig. 1, there were several other companies that participated by way of providing places for secondment of staff. These were mainly drawn from the industrial sites in Harare, purely for convenience. However, there were a few others in neighboring towns and one from South Africa. The secondments were for at least 6 weeks during the mid-semester vacations for the entire duration of the EEEP. A total of 11 academics, 8 technicians and 9 students were gainfully attached at these companies for a total of 534 man days. The second aspect of the EEEP involved professional training where 10 academics were supported to attend Continuous Professional Development (CPD) courses in order to keep pace with technological advancements. The EEEP also provided financial support to engage experts in various fields to provide in-house training to academics and technicians as well as assisting targeted departments to review their curricula in line with industry needs [25]. The third aspect focused on sharing knowledge and experiences among the HEIs as well as practicing engineers from industry. Several workshops and seminars and an end of project conference were held and attended by representatives from various organizations. Assessments were also made to establish the effectiveness of the 3 initiatives and how these impacted on the lecturers' and technicians' abilities and confidence to dispatch their duties.

4. Development of the systems thinking and collaboration model

4.1. Stakeholders

The EEEP initiative was guided by the inclusive participation of all stakeholders in order to address the weaknesses and challenges encountered for sustainable schemes that did not rely entirely on donor support. The key stakeholders identified for the successful execution of the EEEP were HEIs, professional institutions, government, research institutions, industry and cooperating partners. During the knowledge sharing workshops, a number of resolutions were made such as the need for regional integration, collaboration for technology transfer and best practices, accreditation, standardization of curricula to allow for mobility of professional engineers and exchange of staff and students, sharing of resources, both human and capital for cost reductions, all driven by a network of HEIs and industry for regional and collaborative research. For the proposed model to function uninterrupted and sustainably, each of the stakeholders were equated to a cog in gearwheel, such that if it broke, the gear would not be functional. However, the model should be sufficiently robust that if unfortunately, a cog was removed, the model would still be capable of delivering the required objectives, albeit in a modified form. The model was therefore developed on the premise of the functions and expectations of stakeholders as summarized in Table 2, the basis of the systems thinking model.

Table 2. Basis of the systems thinking model: Stakeholders' functions and purposes

Stakeholder	**Functions and Purpose - Expectations**
Higher Education Institutions (HEIs)	Relevant training and exposure to modern practices imparted to students
Research Institutions	Employ graduates from HEIs to solve problems from governments and industry
Industry	Require well trained graduates to run companies in profitable and efficient ways
Governments	Rely on taxes derived from profitable and well-functioning companies
Professional Institutions	Regulated the training of engineers and accredit appropriate HEI programs
Cooperating Partners (Donors)	Provide financial support and facilitate collaborations with industrialised countries

4.2. Cooperating Partners

While regional collaborations were good for joint research and sharing of resources, this may be considered as 'in-breeding' unless it went beyond the region and tapped from the achievements and technologies from the industrialized world [26]. The proposed model emphasized the need to develop links between HEIs in Southern Africa and those in the industrialized world such as the UK. Cooperating partners played an important role in providing financial support as well as facilitating collaborations with HEIs from their countries. Southern African HEIs can also benefit from state-of-the-art research and equipment from the industrialized world [26], while HEIs from the industrialized world can benefit from using their skills to solve challenges faced by Southern Africa.

4.3. Equipment acquisition, utilization and maintenance

Due to rapid changes in technology, engineering and scientific equipment has evolved at the same pace [27]. The traditional supplier companies are normally domiciled in industrialized countries, hence the need for collaborations with institutions in those countries for ease of facilitation in the training and use of the equipment [27]. Industrializing countries can also utilize engineering activities in education and research to introduce appreciable and added value to their resources through income generations such as consultancy work in addition to training students [28]. However, to implement this, required changing the mind-sets of authorities and practitioners, requiring innovations and reforms in engineering education. In the proposed model, industry can enter into contracts with HEIs, with knowledge and capability to carry out research for industry using the equipment purchased by industry for an agreed period sufficient to cover the cost of the equipment, at which point the ownership can be transferred to the HEI.

4.4. Government involvement and promotion of innovations

Following the global financial crisis of 2008, many professional engineers in Southern Africa left their countries in search of better opportunities abroad [29]. In response to the need to reindustrialize the manufacturing sector, the Zimbabwean government offered free tuition to high school students pursuing Science, Technology, Engineering and Mathematics (STEM) subjects in order to bolster the number of school leavers choosing to study engineering. The RAEng has contributed to engineering innovations since 2013 through several competitions such as the Africa Prize for Engineering Innovation [30]. Similarly, the Zimbabwe Institution of Engineers has also promoted engineering education through student competitions [31]. Through these competitions, coupled with the requisite engineering skills, engineering educators and practitioners have provided innovative and affordable solutions to communities with no access to modern technology or basic facilities.

5. Results

The Faculty of Engineering's personnel, most of whom had been seconded to industry, designed and developed a groundwater system at the UZ [32]. The team consisted of professional engineers and technicians drawn from the faculty's departments as shown on the enterprise model in Fig. 2(a). The UZ groundwater project was successfully accomplished by drilling 13 boreholes around the campus following hydrogeological tests on the most suitable sites. This was followed by construction of the pump-house, two storage tanks of 2,500 m^3 each and one 500 m^3 sump for abstracting water from the boreholes as well as installation of two booster pumps. From 2014, the UZ has enjoyed uninterrupted supplies of clean and safe water abstracted from the 13 boreholes within the campus to completely supply a community of 15,000 students and 2,000 staff members. The community involvement of faculty staff saved the UZ in excess of an estimated USD 1 million [32]. The total project costs were mainly materials and hired general labour for trenching and construction. The use of engineering academics and technicians based on expertise acquired from secondments in industry saved the university in professional fees for the design, development and implementation of this enterprise model. The enterprise model created opportunities for a spin-off company to provide such services to other institutions as income generating ventures. The success of this enterprise model prompted the need to expand the scope to other similar ventures such as solar lighting for the entire campus. That way, the systems thinking approach would benefit a wider community and provide income streams for the university.

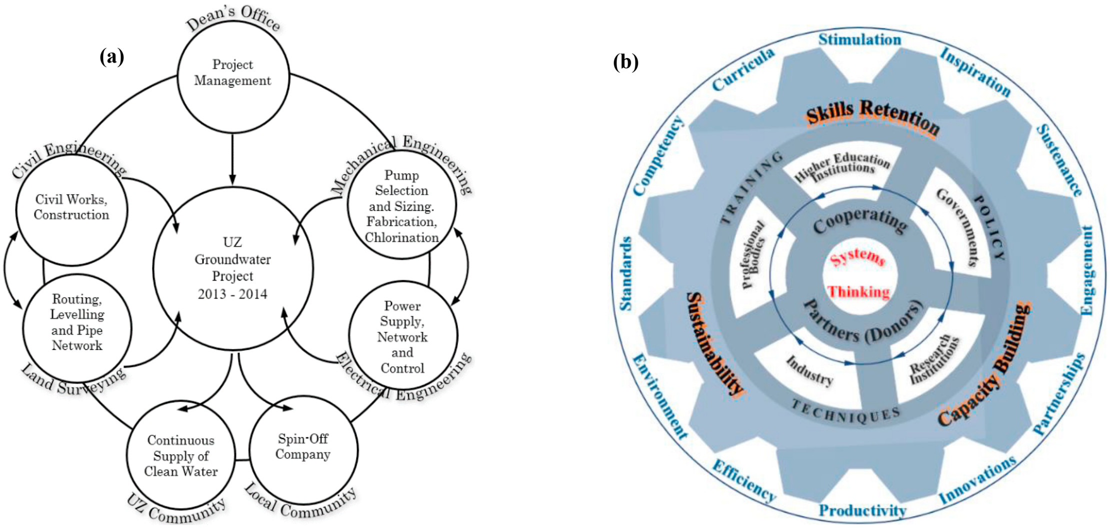

Fig. 2. (a) Enterprise model for the UZ Groundwater Project (b) Proposed systems thinking collaboration model

The intervention of the RAEng was timely in that funds were also provided for the training of 10 academics and technicians in the use of Computer Numerically Controlled (CNC) machines which enabled them to use the acquired equipment for the training of students. Several motivational workshops were also held during the 2-year period where professional engineers made presentations to motivate staff and students. The two experts engaged to evaluate the project concurred that the linkages between industry and academia provided a good standard of education for engineering students as well as recommended appropriate research for development through industrial projects. One of the platinum mining and processing companies offered a fully funded Professorial Chair in Mining Engineering, the incumbent of whom was appointed in 2016 and now mentoring young academics in the faculty. Several workshops and conferences held enabled the sharing of knowledge among institutions as well as interacting with engineers from industry which resulted in a number of industrial based and consultancy projects. The secondments to industry were largely successful and catered for more participants than originally planned because of the in-kind contributions made by companies.

Through the interactions with industry, the UZ benefited through the acquisition of modern engineering equipment in the form of new CNC machining equipment, live GSM telecommunications base station, Day Ahead Marketing (DAM) electricity trading platform and a solar trailer to the institution's laboratories, mostly from companies that participated in the EEEP. This model has strengthened partnerships with industry through the development of long-term frameworks for training, capacity building, and sustainability within the HEIs. The systems thinking model was derived from the elements (stakeholders), functions and purposes as set out in Tables 1 and 2 that produced the 'cogwheel' arrangement and structure as shown in Fig. 2(b). This encompassed the major aspects of techniques, skills training and policies revolving around the six major stakeholders to build capacity, retain skills and sustain these for attributes such as productivity and efficiency in industry, stimulation of interest and development of relevant curricula in HEIs while partnering with professional and research institutions and getting the needed support from cooperating partners, policy makers and government.

6. Discussion and recommendations

Following the end of program conference, participants unanimously agreed to the formation of the Southern Africa Engineering Education Network (SAE^{2}Net) for furthering the original objectives and scaling up the EEEP and NUSESA initiatives. The network will serve as a platform to facilitate collaborations among institutions, pooling of complementary resources, establishment of a regional postgraduate degree in Engineering as well as regional annual conferences and journal. This was also a perfect platform to offer Continuous Professional Development (CPD) to practicing engineers in industry and in the process generating income to sustain network activities. Despite the depressed economies in Southern Africa, various companies that participated in the EEEP expressed enthusiasm and interest to invest in the scheme through such initiatives as the Build Operate and Transfer (BOT) model. The key to economic recovery and reduction in foreign aid dependency was the development of human capital, particularly engineering skills required to revive industries in order to increase capacity utilization and ultimately improve exports. Minerals such as platinum and diamonds are exported from Zimbabwe semi-refined due to the lack of capacity to add value. Collaborations between HEIs in Southern Africa and those abroad can help build the capacity and skills required for beneficiation and value addition. This can be accomplished through the establishment of technology parks or spin-off companies for incubation purposes and appropriate research and development projects to solve industry's challenges. These collaborations can further strengthen such partnerships through technology transfers, academic staff developments and joint research and development. Although participating institutions benefitted from the EEEP, there was no continuity as this could not be sustained beyond the 2-year period without additional support. However, this has been remodeled from the results of this research to Higher Education Partnerships for Sub-Saharan Africa (HEPSSA) where there are now more institutions involved.

7. Conclusions

Southern Africa suffered from a persistent shortage of professional engineers due to inadequacies in training resources, compounded by the flight of the available few engineers to other countries. Although noble initiatives such as NUSESA and EEEP were largely successful, they could not be sustained beyond the funding period. A systems thinking collaboration model that identified key stakeholders necessary for self-sustenance and the smart training of engineers through forging links between academia and industry was proposed. This was developed and has been incorporated in the remodeled and RAEng funded HEPSSA initiative with inclusive participation of more institutions and financial and material support from governments and industry. An enterprise model that was developed on the same principle resulted in the successful and uninterrupted supply of clean water to a university community, through the use of available academic and technical skills. Such models can be used for advocacy to governments and industry to prioritize funding for engineering education and training.

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