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Bridging the Academia Industry Divide

Innovation and Industrialisation Perspective using Systems Thinking Research in Sub-Saharan Africa

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We sincerely dedicate this book to our families and colleagues who made it possible!

To all the engineers and system thinkers who have helped and continue to engineer a better world in a creative and innovative manner, disruptive as it may be, but necessary!

"You cannot carry out fundamental change without a certain amount of madness. In this case, it comes from non-conformity, the courage to turn your back on the old formulas, the courage to invent the future. It took the madmen of yesterday for us to be able to act with extreme clarity today. I want to be one of those madmen. We must dare to invent the future".

–Thomas Sankara (1985):
President of Burkina Faso

"Are engineers better at business than business people? It's debatable. Business people certainly seem to have bigger houses, drive fancier cars, wear nicer clothes and have better looking mates. Engineers lack the time and management skills to spend that kind of money. They waste all their time inventing ways to make the most money in the quickest, most efficient way possible. And then when they figure it out, they optimise the process".

–Raul Perez

Preface

Bridging the Academia Industry Divide: Innovation and Industrialisation Perspective Using Systems Thinking Research in Sub-Saharan Africa is a book that culminated from years of research following a realisation of the gap and mismatch of engineering skills produced by universities and those that industry required. Based on case studies in Sub-Saharan Africa, the initiatives included collaborations and secondments with the aim of bridging the gap between academia and industry through systems thinking research, aided initially by the Swedish International Development Cooperation Agency (Sida) through the Network of Users of Scientific Equipment in Eastern and Southern Africa (NUSESA) (1989–2005). The initiatives were later revamped and supported by the Royal Academy of Engineering through the Enriching Engineering Education Program (EEEP) (2013–2015) and the Higher Education Partnerships for Sub-Saharan Africa (HEP SSA) (2019–2021) in partnership with tertiary institutions in Southern Africa and the University of Leicester in the UK, anchored by SADC governments, regional industry, research institutions, professional engineering and regulatory bodies, out of which the Southern Africa Engineering Education Network (SAE^{2}Net) was established.

The book provides information on how to model, simulate, adjust and implement integrated systems thinking frameworks to improve the quality of engineering education and training for capacity building and sustainability. The book also covers approaches to address research gaps and mismatch of skills while capitalising on the successes of the NUSESA, EEEP and HEP SSA initiatives. The book primarily consists of the novel research and innovation approach of modelling and building systems thinking sub-models which were eventually integrated into the Universal Systems Thinking (UST) model ("bridge") to assist engineering academics and engineers in industry to build capacity and cope with the rapid and dynamic trends in technology in view of the widespread implementation and impact of the 4th Industrial Revolution and in preparation for the Digital Ecosystem, an era predicted to be dominated by critical and system thinkers equipped with creative and innovative skills. The book is also useful for policy-making researchers in academia, industrial and public sector researchers, and implementers in governments that provide required funding for the development of human resources and engineering skills to drive industry. Not only is the book a reference guide for engineering practitioners but is also a cocktail of experiences benchmarked on industrialised and semi-industrialised economies to create a blend and best practices for bridging the gap between academia and industry in industrialising economies.

Johannesburg, South Africa — Wilson R. Nyemba
Harare, Zimbabwe — Charles Mbohwa
Leicester, UK — Keith F. Carter

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We wish to thank the Swedish International Development Cooperation Agency (Sida) who opened the doors to pursue this research through the Network of Users of Scientific Equipment in Eastern and Southern Africa (NUSESA) which formed a firm foundation for the collaborations in engineering education in Sub-Saharan Africa.

Our sincere gratitude and appreciation to the Royal Academy of Engineering who revamped the Sida support and expanded it to include the vital missing link of industry players through the Enriching Engineering Education Program (EEEP) and the scaled up Higher Education Partnerships for Sub-Saharan Africa (HEP SSA). Their decade-long support helped to strengthen the ties between academia and industry in Southern Africa, apart from other support initiatives such as the Industry Academia Partnership Program, Africa Catalyst and the Africa Prize for Engineering Innovation.

We are also grateful for the different contributions made by several industry partners, government ministries, professional engineering and regulatory bodies as well as research institutes in Southern Africa, inclusive of technology transfer, equipment and the UZ-Zimplats Professorial Chair in Mining Engineering. We are equally indebted to the assistance and work carried out by students and engineering academics who were attached or seconded to the different sectors of industry and for the valuable work carried out and information gathered, culminating in several scholarly publications.

Our colleagues from the University of Zimbabwe HEP SSA Implementation Committee (Management) and the regional HEP SSA Steering Committee (Board) contributed immensely in shaping the direction and eventual compilation of this book and the establishment of the Southern Africa Engineering Education Network (SAE^{2}Net).

We are all indebted to our families for the sacrifice and time spent away from them to ensure that this work was completed and above all the Almighty for giving us the strength and wisdom to continue.

"*It always seems impossible until it's done*". – Nelson Mandela.

Wilson R. Nyemba
Charles Mbohwa
Keith F. Carter

Abbreviations

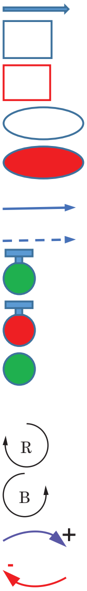
BMR	Base Metal Refinery
BOT	Build-Operate-Transfer
BUSH	Biomass Utilisation by Sustainable Harvest
CNC	Computer Numerical Control
CREEE	Centre for Renewable Energy and Energy Efficiency
CUT	Chinhoyi University of Technology
DAM	Day Ahead Marketing
EDF	European Development Fund
EEEP	Enriching Engineering Education Program
FAO	Food and Agricultural Organisation
GCRF	Global Challenges Research Fund
GSM	Global System for Mobile Communications
GTZ	German Technical Cooperation Agency (GIZ)
HEP SSA	Higher Education Partnerships for Sub-Saharan Africa
HIT	Harare Institute of Technology
HPGR	High Pressure Grinding Rolls
IBL	Industry Based Learning
IDT	Industrial Design Thinking
JICA	Japan International Cooperation Agency
MU	Makerere University
NEED	Network of Energy Excellence for Development
NEPAD	New Partnerships for Africa's Development
NUSESA	Network of Users of Scientific Equipment in Eastern and Southern Africa
NUST	Namibia University of Science and Technology
NUST Z	National University of Science and Technology, Zimbabwe
ODA	Overseas Development Authority
OECD	Organisation for Economic Cooperation and Development
OEM	Original Equipment Manufacturers
PARTICIPA	Participatory Integrated Assessment of Energy Systems to Promote Energy Access and Efficiency

PBL	Problem Based Learning
PhD	Doctor of Philosophy
PMR	Precious Metal Refinery
PPP	Public Private Partnerships
R&D	Research and Development
RAEng	Royal Academy of Engineering
SADC	Southern Africa Development Community
SAE^2Net	Southern Africa Engineering Education Network
Sida	Swedish International Development Co-operation Agency
SPP	Smart Procurement Partnerships
UDSM	University of Dar es Salaam
UEM	Universidade Eduardo Mondlane
UN	United Nations
UNESCO-IHE	United Nations Education, Scientific and Cultural Organisation – Institute for Water Education
USAID	United States Agency for International Development
UJ	University of Johannesburg
UZ	University of Zimbabwe
ZIMDEF	Zimbabwe Manpower Development Fund
ZNDU	Zimbabwe National Defence University

Nomenclature

Au	Gold
c	Concentrate
f	Feedrate
$E(t)$	Residence time distribution for continuous flotation
$F(k)$	Distribution function for mineral types with different flotation rates
H	Half-width
k	Kinetic rate constant for sub-processes
n	Number of replications
N	Number of parts
Pd	Palladium
Pt	Platinum
R	Recovery of minerals at time t
R_∞	Maximum recovery at infinite time
Rh	Rhodium
s	Sample standard deviation
S	Number of stages in a process
t	Time in minutes
ta	Tailings
T_s	Total time in system
T_q	Total queueing time
T_w	Time spent by N parts through W workstations
W	Number of workstations

Symbols



Systems Thinking Process Flow
Systems Thinking Elements
Constraints/Challenges
Process Flow Outputs/Decisions/Functions
Feedback Process for Improvement
Compulsory Link/Interconnection and Direction
Flexible or Optional Link/Interconnection and Direction
Processing: Simulating/Controlling/Optimising
Adjustments
Acceptable Outcome for Decision Making, Conclusions or Recommendations
Positive Reinforcing Feedback Loop
Negative Balancing Feedback Loop
Positive Link/Feedback
Negative Link/Feedback

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About the Authors

Wilson R. Nyemba is a senior lecturer in mechanical engineering at the University of Zimbabwe with over 30 years of experience both in industry and academia. He designed and developed a wide range of engineering products in different capacities in industry from product development to engineering management. He also formulated and led a number of successful ventures at the University of Zimbabwe where he served as Dean of the Faculty of Engineering. He also served as Chairman of WaterNet and project manager for the Royal Academy of Engineering projects for enhancing the quality of engineering education in Southern Africa. He is an accomplished consultant and researcher with interests in engineering education, capacity building and sustainability, systems thinking and modelling. He holds a BSc honours degree in mechanical engineering from the University of Zimbabwe, an MSc degree in advanced mechanical engineering from the University of Warwick in England and a Doctor of Engineering degree in mechanical engineering from the University of Johannesburg in South Africa. He is also currently co-appointed as a senior research associate in the Department of Quality Assurance and Operations Management at the University of Johannesburg. He has authored and published 55 peer-reviewed papers in journals and conference proceedings as well as several consultancy reports. He has received several awards and recognition for outstanding research.

Charles Mbohwa is the University of Zimbabwe pro-vice chancellor responsible for strategic partnerships and industrialisation as well as a visiting professor at the University of Johannesburg. He previously worked for the National Railways of Zimbabwe and the University of Zimbabwe as a senior lecturer and head of Department of Mechanical Engineering. He has extensively published papers in peer-reviewed journals and conferences as well as book chapters and 5 books. He holds a BSc honours degree in mechanical engineering from the University of Zimbabwe, a Master of Science in operations management and manufacturing systems from the University of Nottingham and a Doctor of Engineering from the Tokyo Metropolitan Institute of Technology in Japan. He was a Fulbright scholar in 2006–2007 at the Supply Chain and Logistics Institute, School of Industrial and Systems Engineering, Georgia Institute of Technology, as well as a Japan Foundation fellow. He is also a reviewer for more than 20 international journals and is a member of the editorial boards/committees of 5 journals.

Keith F. Carter is a chartered mechanical and nuclear consultant engineer who has also trained as a naval architect. He is a director and principal consultant for Keimar Consultancy in Leicester, England. Over the last 15 years, Keith has been associated with a wide variety of engineering projects for Rolls-Royce at Derby, England, in both the nuclear marine and aerospace divisions principally specialising in structural integrity issues. He has also carried out other significant projects in a variety of fields, including the analysis of AGR graphite cores for British Energy (EDF). Dr. Carter also holds the post of visiting design professor within the School of Engineering at the University of Leicester in England, bringing in considerable engineering and industrial experience to the teaching of students and to various research projects. He holds a Bachelor of Science degree in chemistry and a PhD in statistical mechanics using computer simulation, both from the Royal Holloway College at the University of London and has authored over 30 academic papers as well as numerous reports for client companies.

Chapter 1
Introduction

Abstract Skills deficits in engineering, science and technology throughout the world require innovative strategies in order to drive industry in view of the rapid changes in technology and the demands for the fourth industrial revolution and prepare for the Digital Ecosystem. Several initiatives have been developed and implemented to improve the quality of engineering education. However, while most of these initiatives have been quite helpful, particularly in Sub-Saharan Africa, one major limitation was lack of continuity. This chapter analyses some of these initiatives as a base for the research by focussing on the achievements, shortfalls and scaling-up for sustainability. The chapter also focusses on how engineering education has been affected by the rapid trends in technology vis-a-vis macro-economic situations and policies for engineering skills development. This synopsis was aimed at developing strategies to ensure that the acquisition of engineering skills at tertiary institutions was done in such a way as to match those required by industry.

Keywords Collaborations · Education · Engineering capacity · EEEP · HEI · HEP SSA · Industry partnerships · Mismatch and shortage of skills · NUSESA · Skills development · Sustainability · Training

1.1 Research Background

According to studies carried out in various countries in Sub-Saharan Africa such as Malawi (ICE and GDC 2002a), Mozambique (ICE and GDC 2002b), Rwanda (Goodsir et al. 2009), South Africa (Lawless 2007), Tanzania (ICE and GDC 2002c), Nigeria, Ghana and Zimbabwe (Afonja et al. 2005), the region has been heavily affected by a perennial and persistent lack of adequate engineering skills and capacity to drive the various sectors of industry. Not only did the studies reveal shortages

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of engineering skills but also inadequacies in the education and training of engineers due to the use of old equipment and outdated technology, which often resulted in mismatches of skills imparted to graduates and those required by industry (Bubou et al. 2017). This was exacerbated by the wide gap between academia and industry (Matthews et al. 2012) as well as the high dependence on the limited foreign aid, which often resulted in the lack of continuity or sustainability in engineering education and training. More recently and despite having over 20 Higher Education Institutions (HEIs), a national critical skills audit revealed that Zimbabwe had an average skills deficit of 62% but more specifically over 90% for science and technology (Government of Zimbabwe 2018).

1.2 Initiatives to Enhance Engineering Education

Foreign aid dependence for Sub-Saharan Africa dates back to the colonial era of the early to the late 1900s. Western governments provided all the necessary and required support for both tertiary institutions and industry. This ranged from skilled personnel to machine tools and infrastructure. Workshop and laboratory equipment and staff for most of the engineering faculties were supplied as part of the agreements to establish these institutions as colleges of universities mostly from Europe. These were supported by aid agencies such as the Overseas Development Authority (ODA) for countries such as Zimbabwe, Zambia, Malawi, etc. that were under British rule (Zinyemba 2010), while the Organisation for Economic Cooperation and Development (OECD) supported countries such as Angola and Mozambique that were under Portuguese rule (Macauhub 2013). With time and as the colonial countries became independent, the colleges were weaned off to run as independent institutions while the expatriate staff gradually returned to their home countries (Zinyemba 2010). Regrettably, in many of the cases, no sustainability plans were left in place to ensure continuity.

Although the ODA continued to support staff development at tertiary institutions through scholarships to study abroad, the equipment that had originally been provided was not replenished, leading to deterioration, obsolescence and in some cases underutilisation due to lack of expertise. According to the World Bank (2010), this was worsened by recession, particularly in Southern Africa during the period 2000–2010, which inevitably forced some of the trained and skilled personnel to flee the region for greener pastures abroad. The other reason for failure to replenish or maintain the equipment was the limited financial capacities by the local institutions as they relied almost entirely on government grants that came from scarce government resources.

As such, although some of the equipment was still functional, most of it had gone beyond 25 years, hence outdated technology which contributed to the mismatch of skills from tertiary institutions and those that industry required. This also resulted in the production of engineering graduates who may have been qualified but unemployable. The underlying philosophy of the industrial revolutions was the rapid changes in technology at a much faster pace than it did a few years ago. This trend forced Original Equipment Manufacturers (OEMs) to modify laboratory and engineering equipment and in some cases completely change the machine tools and the technologies that drove them (Martinez et al. 2010). While global competition forced the OEMs to reduce their equipment prices in order to remain profitable, the cost of new equipment remained unaffordable to tertiary institutions in the industrialising world (Allais and Gobert 2016). The introduction of microchips, robotics and machine learning has considerably simplified operations in the fourth industrial revolution (Broadbent and McCann 2016).

However, such changes and complexities required continuous professional development of the users as well as those training new engineers to drive these systems in future, a costly requirement especially for industrialising countries (Ahuja and Khamba 2008). In most cases, expertise to train these could only be found at the OEMs. In addition, the maintenance required regular calibration, thus more problematic compared to conventional machines (Ju 2012). While countries in the industrialised world, where the OEMs are domiciled, could cope with these changes and afford to replenish their machine tools in tandem with rapid changes in technology, in the industrialising world, such as most of those in Sub-Saharan Africa, this was a costly challenge. In addition, lack of synergies and formal links and collaborations between industry and academia created another cost centre for prospective employers who ended up training engineering graduates beyond what they would have done had there been adequate grounding before graduation (World Bank 2010). Most of these challenges demotivated academics and students who advertently lost interest or developed a fear for working with machines. All these challenges partly contributed to the need to establish projects such as the Network of Users for Scientific Equipment in Eastern and Southern Africa (NUSESA), financially supported by the Swedish International Development Cooperation Agency (Sida), the Enriching Engineering Education Program (EEEP) and the Higher Education Partnerships for Sub-Saharan Africa (HEP SSA), both funded by the Royal Academy of Engineering of the United Kingdom.

1.3 NUSESA, EEEP and HEP SSA

Research output in the region was seriously affected by obsolescent equipment and lack of skills to maintain the same, prompting the establishment of NUSESA in 1989, supported by Sida with five founding members, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe, and by the new millennium, the membership had risen to 14 (Lindgren 2001). The establishment of NUSESA was aimed at developing long-term strategies for sustainability through the improvement of procurement, use and maintenance of scientific equipment while building capacity through the development of collaborative training, research and exchange of staff among the faculties of engineering in Eastern and Southern Africa (Lindgren 2001). A secretariat was established for the initiative and was based at the University of Zimbabwe, coordinating the sharing of equipment and exchange of skilled staff in the use and maintenance of the equipment. However, this initiative could only survive during the period of financial support from Sida, purportedly due to the failure to put in sustainability plans for the initiative and the failure to secure support from local and regional governments. Despite funds running out after the first 5 years of NUSESA, the project continued with resources derived from member institutions until the mid-2000s when it could not be sustained by local and regional governments. However, engineering academics in Sub-Saharan Africa continued to engage with their counterparts in the United Kingdom.

Initiatives such as the Africa-UK Partnership for Development supported by the Department for International Development (DFID) (Matthews et al. 2012) were established. From these engagements, engineering managers revealed the lack of engineering capacity and capability in Southern Africa as the main bottleneck to meeting the economic, social and environmental needs of nations within the region (Matthews et al. 2012). Additionally, inadequate infrastructure and a shortage of engineers coupled with a mismatch of skills affected the region's ability to tap into its abundant resources, such as solar radiation, minerals and agricultural land, in order to meet the UN Sustainable Development Goals. Since then, the Africa-UK Partnership for Development engaged extensively with engineering communities in the region through thematic workshops and a search for long-lasting solutions to enhance the quality of engineering education and the acquisition of appropriate skills to drive industry.

The continued engagements with the Africa-UK Partnership for Development saw the Universities of Zimbabwe (UZ) and Dar es Salaam (UDSM) being awarded grants by the Royal Academy of Engineering (RAEng) to enhance the training of engineers both for academia as well as industry under the auspices of a 2-year project (2013–2015), Enriching Engineering Education Program (EEEP) (RAEng 2017a). The project operated on a hub and spoke arrangement where UDSM and UZ were the hubs for Eastern and Southern Africa, respectively, while other regional institutions were the spoke institutions. In order to enhance the skills for engineering academics, the programs in the two regions focussed on continuous professional development training to raise the standards of academics' skills in tandem with changes in technology, research collaborations and sharing of experiences in the region through knowledge-sharing workshops and conferences, as well as secondment to industry to familiarise with modern equipment, systems and technology.

The objectives were all largely achieved and successful as demonstrated through feedback seminars where young and inexperienced engineering academics expressed their satisfaction and confidence in delivering their duties as lecturers. This was also evidenced by student evaluations at the end of semesters. A significant number of industry-based projects were generated as a result of the interactions and secondments. Some of the significant achievements from the EEEP included the UZ's engineering academics' development of a groundwater project to supply the entire campus of 20,000 students and 5000 staff with uninterrupted supplies of clean water abstracted from 13 boreholes that were sunk around the campus. This community service provision by engineering academics consisted of four main segments, that is Geoinformatics and Surveying for designing of the pipe routes and levelling, Civil Engineering for excavations and construction of the sump and pump-house, Mechanical Engineering for all the pump-house pipe fabrications and installations and setting up the purification plant and electrical engineering for the design of the electrical network and control system.

The project was commissioned in 2014 and has been running uninterrupted, providing a solution to the perennial problems of water shortages on campus. The other significant result was the provision of a fully funded Professorial Chair for Mining Engineering by Zimbabwe Platinum Mines (Zimplats), one of the industry partners in the EEEP. The position was filled in by a professor from Penn State University in the United States and provided a perfect link between industry and academia as part of the requirements for the position, that is mentoring young engineering academics while also providing a service and solutions to industry. The continued interactions between industry and academia not only saw more industry partners coming on board with various interventions such as provision of scholarships for students and places for attachment (students) and secondments (academics) but also resulted in the UZ engaging a full-time Industrial Liaison Officer to provide the bridge between all industry players and the institution.

Following the successful execution of the EEEP and the various interventions as articulated above, the RAEng upscaled their support to have more hubs and spokes in both regions, Eastern and Southern Africa under the new grant for Higher Education Partnerships for Sub-Saharan Africa (HEP SSA) from 2016 (RAEng 2017b). More recently, the UZ in partnership with seven other institutions in the region, that is Chinhoyi University of Technology, National University of Science and Technology, Harare Institute of Technology and the Zimbabwe National Defence University from Zimbabwe and the University of Johannesburg, Universidade Eduardo Mondlane and Namibia University of Science and Technology together with the University of Leicester as the UK partner, as well as five industry partners from Zimbabwe, successfully applied for another grant from the RAEng to expand the scope for enhancing the quality of engineering education through a broad and expanded version of the objectives. This book focusses on building on those objectives and achievements from NUSESA, EEEP and HEP SSA by outlining a cocktail of engineering change management techniques using systems thinking in handling problem-based learning (PBL), industry-based learning (IBL) for capacity building and sustainability of these noble initiatives.

1.4 Macroeconomic Situations and Policies

The need to bring industry closer to academia was prompted by the global financial crisis of 2008 which had a severe impact on most countries in Southern Africa (Bakrania and Lucas 2009). Many companies, especially those in engineering and manufacturing, scaled down operations. In some cases, some of these companies were liquidated or their capacity utilisation negatively affected. Despite having